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PAPER MAKING

PAPER MAKING

A GENERAL ACCOUNT OF ITS HISTORY, PROCESSES, AND APPLICATIONS

Prepared under the Direction of the Education Committee of the Technical Section of the British Paper and Board Makers' Association (Incorporated)

THE TECHNICAL SECTION OF THE BRITISH PAPER
AND BOARD MAKERS' ASSOCIATION
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PREFACE

In December 1944 the Technical Section of the then Paper Makers' Association of Great Britain and Ireland formed a Sub-Committee, the terms of reference of which called for suggestions regarding the manner in which "the best contributions could be made by the Technical Section towards education for the Industry."

The First Report of this Sub-Committee appeared in March 1945; and it contained a recommendation that steps should be taken to produce text-books on paper making with special reference to British methods and at a relatively low selling price. This suggestion was accepted by the Executive Committee of the Technical Section and passed on to the Executive Council of the Paper Makers' Association, and in September 1946 this body, on the recommendation of its own Education Committee, voted a financial grant for the purpose of launching the scheme.

It was decided that the first publication should be a relatively elementary, general account of paper making, covering its history, processes and applications, and that it should be addressed primarily to the younger members of the Industry, to those thinking of entering the Industry, and as a guide to those employed on the commercial side and in associated industries.

This present volume is the result. Each section or chapter has been written by an expert in the branch of paper making with which it deals; and every effort has been made to combine simplicity of expression with accuracy. It will be noted that the whole range of paper-making knowledge, from pulp manufacture to converting processes, has been covered, but in doing so due prominence has been given to British methods. Features which, it is hoped, will be of special help to readers are the list of books for further reading and the glossary of paper-making terms. The illustrations have been chosen carefully so as to ensure a full understanding of the text and to convey to the reader some idea of what the plant described is actually like.

It is proposed that this first volume shall be followed by a series of short monographs each dealing with one particular branch of paper making, but on more advanced and specialised lines. It is hoped that it will be possible to publish these at a price well within the reach of every paper-mill worker. In this way it will be possible for all concerned to build up gradually a library of up-to-date and authoritative information on paper making at a relatively small cost.

The Editorial Committee take pleasure in conveying their best thanks to the contributors to the present volume (listed on p. ix) who have so generously given valuable time for this work in the interests of the Industry. Great help has also been received from other individuals and firms listed below, and from Mr. F. M. Bolam, B.Sc., A.R.I.C., Secretary of the Technical Section; to these also the Committee's best thanks are due.

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CHAPTER I

INTRODUCTION AND HISTORICAL

The consumption of paper per head of a nation's population has been suggested as an indication of the degree of civilisation which that nation has attained. Certainly world development as we know it could not have taken place without a means of communication between men in which speech is supplemented by written or printed records. Paper has undoubtedly been the principal medium for such records.

Writing Materials Preceding Paper

In the earliest days the materials used for writing and drawing were numerous. Stones, clay tiles, bones, metals, skins, leaves of certain plants, waxed wooden tablets, linen and silk fabrics were all used, but, with the exception of *papyrus* and *animal parchment*, had obvious limitations.

Papyrus was prepared from the water reed of this name which grows on the banks of the Nile, and specimens bearing written characters have been found in Egyptian tombs of 3500 B.C. The method of preparation has been a matter of dispute; some state that slabs were cut diametrically across the stem, whilst others suggest that layers were peeled from the surface like the layers of an onion. Probably only the outer skin was used, because the reed as we know it to-day consists only of an outer skin with a pithy interior. Apparently the strips so obtained were laid side by side on a stone slab. More strips were placed on them, but with their directions at right angles to those of the first layer, and so on. The whole mass of layers was moistened, either with water or with an adhesive, and pressed and dried. The dried material was hammered to make it more compact and rubbed with a smooth stone or bone to produce a smooth surface. The importance of papyrus will be realised from the fact that most of the works of the great Greek and Roman scholars were written upon it and that its use persisted until about the ninth century A.D.

Although the skins of animals had been used for records from much earlier times (the library of Ptolemy Philadelphus in Alexandria in the third century B.C. is said to have consisted of the skins of serpents), it was not until about 170 B.C. that King Eumenes of Persia used them to produce animal parchment. The skins used were mainly those of domestic animals, such as calves, sheep and goats, and the younger the animal the finer was the product. The washed skin was stretched on a wooden frame and coated with a paste of chalk and lime to remove grease and loosen hair. On drying the paste flaked off, and the skin was scraped with a curved knife and rubbed with pumice until smooth and uniform. The finer products of the process (which is still in use) were formerly known as *vellum*. This is curious, as to-day vellum usually describes the coarser kinds, which are mainly used for book-binding.

Early History of Paper

The origin of paper making is somewhat obscure, but certainly it occurred in China. Traditional Chinese records give the credit, for its development at any rate, to Tsai Lun (about A.D. 105), who was even deified as the god of paper makers. One Chinese record states that he " . . . first made paper by pulping fishing nets and rags. Later he used the fibres of plants; any which proved sufficiently elastic in tension were used as the raw materials for paper. The raw materials were first well boiled and then beaten into a mash. They were then stirred into a pulp and spread on a straining frame or basket. When it had formed a thin tissue the resultant paper was then pressed with heavy weights." Sir Aurel Stein, in 1904, discovered certain letters in Turkestan, in one of the ruined towers of the Great Wall of China, which are believed to have been written within fifty years of the date of the invention on what has proved to be rag paper.

The beating appears to have been done by hand, either with a pestle and mortar or with a wooden mallet on a stone slab. The straining frame or mould consisted of a mat of thin reeds sewn together with silk or horsehair, laid on a light wooden frame and held in place with two strips of wood. The sheet was formed either by dipping the mould into a vat containing a suspension of the pulp or the suspension was poured on to the mould. The sheet was dried either by hanging it in the air or by pressing it on a slab of porous material. Samples in the British Museum indicate that the standard of quality of the early Chinese paper was high, and comparable even with that of paper made to-day.

Eastern civilisation developed more or less simultaneously with the civilisations of the Middle East and of Europe, but as if in a separate world. That is the reason why paper, which was in general use in China nearly 2,000 years ago, was unknown further west until the capture of Chinese prisoners by Arabs at Samarkand in the eighth century. In A.D. 793 a factory was working at Baghdad, where Haroun-el-Raschid introduced Chinese workmen. The next centre was Damascus, which was the main source of supply for Europe for several centuries (particularly of that paper known as Charta

Damascena). From Damascus the art travelled westwards, by way of Egypt, to Morocco. In Egypt, in the ninth century, paper gradually displaced papyrus, which had been the common writing material for about 3,000 years. From Morocco (in about A.D. 1100) the Moors introduced the art into Europe. They were also responsible for the *stamping mill* at the town of Xativa in about 1150, the first example of the use of other than human power for the disintegration and beating of the fibrous raw material. A stamping mill is illustrated in Fig. 1.

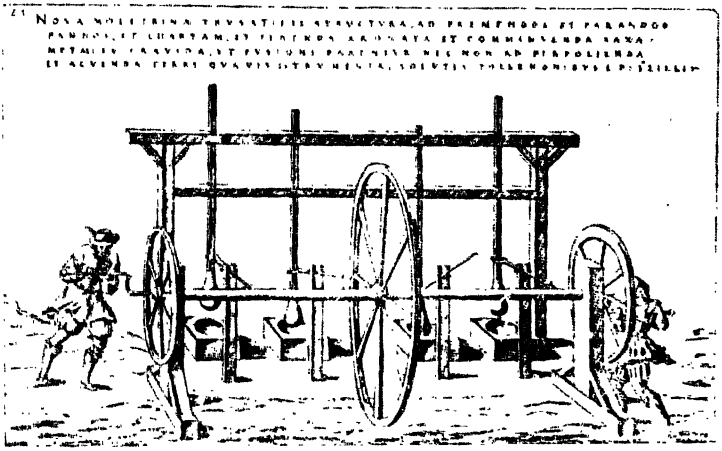

Fig. 1.—STAMPING MILL (1579).

The further progress of the art will be appreciated from the following table, showing the dates (doubtful in some cases) of the earliest mills in various countries :

Spain (Xativa)	A.D. 1150
France (Herault)	„ 1189
Italy (Fabriano)	„ 1260
Germany (Nuremberg)	„ 1389
Switzerland (Marly)	„ 1400
Belgium	„ 1407
Holland (Gennep)	„ 1428
Great Britain (Hertfordshire)	„ 1490
Sweden (Motala)	„ 1532
Denmark	„ 1540
Russia (Moscow)	„ 1690
U.S.A. (Germanstown, Pa.)	„ 1690
Norway (Oslo)	„ 1698

The Italian mills of about 1270 made two valuable contributions to paper making, namely, the use of glue for the tub-sizing of the paper, necessitated presumably by the replacement of the earlier carbon-black inks by iron gallate inks; and the introduction of watermarking, the device by which the maker of a paper can frequently be identified (see Chapter IX).

History of Paper Making in the United Kingdom

Although paper was used in England early in the fourteenth century, the first reference to a mill in the country was in a book printed by Caxton in about 1490. This mill belonged to John Tate, and is supposed to have been near Stevenage in Hertfordshire. Confirmation that a certain Tate had a paper mill in 1498 is provided by an entry in the household book of Henry VII. In 1588 Sir John Spielman had a paper mill at Dartford, and was granted special privileges by Queen Elizabeth regarding the collection of rags and other fibrous raw materials. Another mill was built in Buckinghamshire, apparently before the close of the sixteenth century. Recent researches have shown that in the reign of James VI of Scotland, afterwards James I of England, small mills were established near Edinburgh. Evidence also exists of a mill at Cannock Chase in Staffordshire at this time; and by the middle of the seventeenth century several mills apparently existed in Buckinghamshire, Oxfordshire and Surrey.

These early mills do not appear to have been very successful; one reason was the current belief that the discarded rags used by paper makers helped to spread the plague. However, the influx of Huguenots from France following the revocation of the Edict of Nantes in 1685 brought fresh blood into the industry, and led to the manufacture of watermarked paper for the Bank of England at Whitchurch, Hampshire, in 1724; this mill is still operating.

An outstanding mechanical development took place in Holland about the middle of the eighteenth century. This was the invention of the rag-engine or *hollander*. It replaced the stamping mill that hitherto had been used for the disintegration of the rags and the beating of the pulp. Essentially it consists of an oval-shaped vessel, with a partition partly along its length so as to convert it into an endless trough. On one side is a roll mounted on a shaft and having on its periphery a number of wooden or metal bars parallel to the shaft. Underneath the roll is a box filled with similar bars. As the roll revolves it circulates round the trough the rags or other material which are in suspension in water, and at the same time the height of the roll is adjusted so that the material is hammered and distintegrated between the moving and fixed bars (see Chapter VII).

Another improvement at about the same time was in the mould used for forming the sheet (see p. 119). The reeds in the early moulds had been replaced by straight wires, which were sewn down to the wood foundation. The result was to produce a paper showing corresponding *laid* marks (see p. 128) both on the surface of the sheet and when it was examined by transmitted light. The irregular surface caused trouble in that when printed upon the ink did not yield clear, sharp lines. In order to overcome this defect Baskerville, a stationer of Birmingham, suggested the use of a woven wire fabric in place of the straight wires, thus leading to the production of *wove* paper in 1750.

The first effects of the industrial revolution in the second half of the eighteenth century were felt particularly in the cotton, wool and iron trades, and indirectly in the paper industry. There was a great increase in population and at first, because of the new textile developments, an increase in the supplies of raw materials such as rags, the shortage of which had always been a source of difficulty to paper mills. This latter was, however, but a temporary phase, for by the end of the eighteenth century the shortage of raw material was as great as ever, because the growth of industry increased the demand for papers of all kinds, both for home and for the growing export trade. There was more correspondence, the educated classes bought more books (the eighteenth century being a literary age), and more account books were required.

The daily press, which came into real being at the beginning of the eighteenth century, was increasing, and although there was no national free education until 1870, increasingly more paper was required for school-books and writing materials. Education provided by religious and charitable bodies on a voluntary basis was at the same time spreading throughout the poorer classes. The consequent demand for rags for the manufacture of paper for these purposes could not be satisfied. The Napoleonic wars of 1793 to 1815 increased the difficulty of importing foreign raw material. In 1800 24 million pounds of rags were being used annually, and a good proportion of these were imported, mainly from the Continent.

Réaumur suggested in 1719 that it should be possible to make paper from wood. In 1765, at Regensburg, Jacob Christian Schäffer, a divine and a doctor of philosophy, gave (in his book "Papierversuche") an account of his experiments on the preparation of paper from various substances of vegetable origin. The book includes eighty-one samples made from such materials as the seed hairs from black poplar, wasps' nests, sawdust, moss, spruce wood, rye straw, cabbage stumps, aloe leaves and peat. Schäffer admitted that some of these were tried merely from curiosity, but he showed that it was practicable to make paper from them on an experimental scale. A few years earlier, in 1756, it is stated, straw was being used for making wrapping papers and possibly boards in Germany; however, no attempt was made to obtain a white pulp. In 1800 Matthias Koops published in London his "Historical Account of the Invention of Paper," which was printed on papers made from straw, wood and other fibres. In neither case would the paper be described to-day as a satisfactory printing paper; the colour was poor and much undisintegrated material was present. Koops took out a patent for the pulping of straw in 1802. In his book he also mentions the repulping of old papers for remaking into new paper.

Until the end of the eighteenth century white papers could be made only from white rags, as no practicable method of bleaching the pulp had been devised. In one way this was an advantage, as it avoided deterioration of the paper by the bleaching agent, although it accentuated the shortage of good rags. The discovery of chlorine by Scheele in 1774 and the invention of bleaching powder by Tennant in 1779 led to the use of bleaching processes and enabled coloured material to be used for the production of white papers. This eased slightly the problem of supplies, but it led to the production of papers which tended to deteriorate due to attack by the bleaching solutions, and to complaints of the quality of the paper. At this time comparatively little was known of the action of bleaching agents, but later investigations have shown that it is possible to bleach pulps with little detriment to the permanence of the paper (see Chapter VI).

The Paper Machine.—The increase in population and the spread of industry, commerce and education still further augmented the demand for paper, with a consequent increase in the number of mills. Thus at about the end of the eighteenth century there were 416 in England and Wales, 49 in Scotland and 60 in Ireland, but nearly all of these were small. All the paper was made by hand, so although the quality was usually high, output was low, and it is not surprising that attempts were made to replace the old methods by machinery. The most important of these was that made, in 1799, by Louis Robert, a clerk at the mill of Didot Frères at Essonnes, in France (Fig. 2). A model of his machine can be seen in the Science and Art Museum in South Kensington, London. The effort was not a success, but the idea was passed on, through an Englishman, John Gamble, to a London firm of stationers, owned by the brothers Henry and Sealy Fourdrinier, who engaged the engineer Bryan Donkin of the firm of Donkin and Hall of Dartford. After many trials and much expense a machine was erected at Frogmore, Hertfordshire, in 1803. Although it was based on the ideas of Robert, many changes had been made in the design, and it is probable that much credit for its success is due to Donkin. Unfortunately expenses were so high that, so it is said, the Fourdriniers lost a fortune, but their name is and will be familiar to many generations of paper makers for their share in the development of a machine the essential principles of which are in use to-day.

Compared with present-day standards the Frogmore machine was small. Its wire was 48 inches wide and 27 feet long. Output was about 600 pounds in 24 hours. The paper was formed on an endless wire cloth, pressed on a felt and reeled up in the wet state, to be subsequently unreeled, cut into sheets and loft-dried, as was the custom with the hand-made paper of those days. A second machine was erected in the following year at the Two Waters mill in the same neighbourhood. In 1808 Gamble assigned to the Fourdriniers his share in the patent which had been taken out, but the firm failed in the same year. The success of the machine can nevertheless be gathered from the fact that by 1830 one-half of the paper made in this country was made by machine.

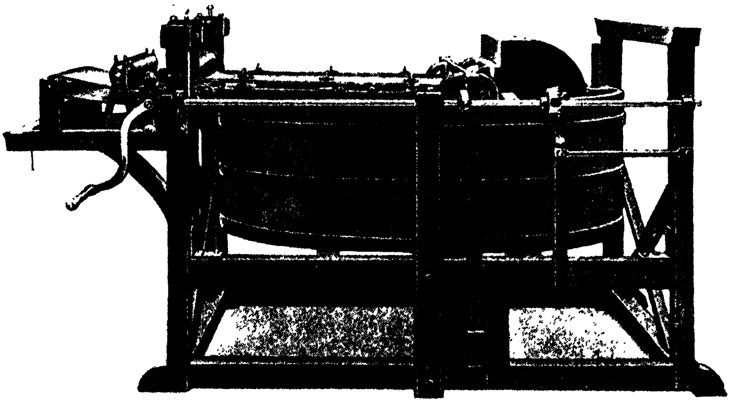

Fig. 2.—Early Paper Machine (reconstructed).

Revolving paddles under the hood (right) throw pulp from the vat on to the wire ; the wet web is removed by hand (at left), and dried separately.

Another type of machine for the formation of paper was patented in 1809 by John Dickinson. In this case the sheet was formed not on a flat wire cloth, as on the Fourdrinier machine, but upon a wire-cloth covered cylinder which revolved in a suspension of the pulp, the filtered water being withdrawn from the inside of the cylinder and the layer of pulp removed from its surface by means of a felt-covered roller. This machine was the forerunner of the present-day *cylinder* or *vat machine,* which to-day is used mainly for the manufacture of boards (see Chapter X).

Until 1821 all the machines produced paper as a wet sheet which required drying after removal from the machine, but in that year T. B. Crompton took out a patent for a method of drying the paper continuously after it had been pressed, and for cutting it into sheets. As at present, the sheet was held by means of a woven fabric against steam-heated drying cylinders.

In 1806 Illig, a German, found that instead of tub-sizing a paper by dipping it into a bath of glue or gelatin, as had been the practice since the twelfth century, the sheet could be sized by adding rosin to the pulp while it was being beaten. This method of *engine sizing* had the advantage that it rendered unnecessary an extra operation after the paper had been made, and therefore it cheapened the process appreciably. Unfortunately rosin confers no increase in strength on the paper (as tub-sizing does), but in spite of this the resulting advantages rendered gelatin sizing obsolete for all except the highest qualities of paper (see Chapter XI).

Modern Raw Materials.—The shortage of fibrous raw materials had troubled paper makers before the introduction of paper machines (see p. 15), but the enormously increased capacity for production now rendered the problem really serious, and substitutes for rags were sought in all directions.

In 1838 L. Piette published, in Cologne, a book in which he described the manufacture of bleached straw pulp, and in which are a large number of samples, some made from straw alone and others from straw mixed with rags, many of them having a good white colour. He also made papers, though presumably on an experimental scale, from other materials, including maize stalks, hay, peat, bamboo, jute, stinging nettles, leather, wood, bark from trees and even tree leaves. During the next fifteen years methods for pulping straw were also developed in France; in particular Mellier patented a successful process for bleached pulp.

In 1844 Keller, with the help of Voelter, in Germany, developed the process for the manufacture of *mechanical wood pulp.* Formerly mechanical processes for pulping depended on the hammering or stamping of the raw material. Keller, however, found that a better pulp was formed when the wood was held against a revolving grindstone, with a stream of water to wash away the particles of fibre as they were scraped off the surface (see Chapter V). Compared with the pulp that had been obtained from rags this mechanical pulp was distinctly inferior, as the fibres were shorter and less pliable, but the product was comparatively cheap and the potential supplies were large. Paper made from such pulp was weak and brittle, but much of it had only an ephemeral existence; and so long as the pulp was not used for papers intended to be durable or permanent, it fulfilled a demand. Unfortunately the use of such paper led to the condemnation of all wood pulps, though such criticism should have been confined to mechanical wood pulp.

In the same year (1854) as that in which Mellier introduced his process for pulping straw, Watt and Burgess patented a similar process for producing pulp from wood by treatment with caustic soda. This *chemical pulp* had a character entirely different from that of the mechanical pulp. The non-fibrous portion of the wood was dissolved away, leaving the fibres more or less whole and flexible, so that the pulp yielded a superior paper. Another chemical (acid) process for wood was that employing bisulphites patented by B. C. Tilghman in the U.S.A. in 1866, and first operated successfully on the large scale in England by C. D. Ekman, at Northfleet in 1887. A few years earlier, in 1860, Routledge introduced the use of esparto grass, cooked with alkali, into the United Kingdom.

Though not confined to particular countries, each of these materials developed mainly in certain areas. Thus, the timber-producing countries (*e.g.* Scandinavia and North America) produced most of the wood pulps; straw found employment chiefly in agricultural countries such as Germany, Holland and France; while esparto was imported into the United Kingdom from Northern Africa and Spain. The Scottish mills, in particular, largely on account of their expert use of esparto, excelled in the making of high-class printing papers, for which this fibre is especially fitted (see Chapter II).

Exploitation of the new sources of pulp was rapid. The imports of esparto into this country in the year following the repeal of the Paper Excise Duty in 1860 were only 16 tons. By 1887 they had risen to 200,000 tons, and in the years prior to the 1939–45 war over 300,000 tons annually were used in 41 mills making esparto paper and boards. Many of these mills were in Scotland, especially in the neighbourhood of the great printing centre of Edinburgh, and much of the paper was exported. The growing importance of wood pulps is seen from the figures for imports into the United Kingdom. In 1885 these were between 30,000 and 40,000 tons. From 1888 onwards more accurate figures are available. Some examples are given in the Table on p. 20.

In the United Kingdom straw was used in white papers only rarely until the 1914–18 war, when in a few mills it helped out the restricted supplies of esparto. During the war of 1939–45, however, the mills which had formerly used esparto found themselves without supplies, and they used as much straw as conditions permitted.

This does not imply that straw can take the place of esparto for high-class printing paper; it does not readily yield as soft or as supple a sheet, and the yield and throughput are less. The mills equipped for esparto were, however, the most suitable for handling the straw. At present (1949) there is a likelihood for some years to come of a shortage of wood pulp, owing to labour, exchange and coal difficulties; it would not be surprising, therefore, if some mills continue to digest straw.

Year	*Tonnage*	*Value in £*
1888	111,000	681,000
1893	216,000	1,184,000
1898	405,000	1,894,000
1908	523,308 (air dry)	3,625,808
1913	977,757	4,617,739
1923	1,133,482	10,127,912
1928	1,283,454	8,471,512
1933	1,939,036	7,941,640
1938	1,617,961 (air dry)	14,237,550.

Developments in the Nineteenth and Twentieth Centuries.—The development of wood and other pulps and the increase in the capacity of the machines led to changes in the number and locations of mills. As stated on p. 16, the number of mills in the United Kingdom at the end of the eighteenth century was over 500. In 1884 there were 250 in England and Wales, 14 in Ireland and 60 in Scotland. However, by 1904 the numbers had decreased to 211 and 8 for England and Wales, respectively, whilst that for Scotland was unchanged; production was gradually being concentrated into larger units. Many of the older mills were small and situated in rural districts, where the original attraction was a copious supply of clean water with, possibly, a stream to provide cheap water power; however, they were distant from fuel supplies, the heavy chemical industries and the paper markets. The only mills of this type that could withstand competition were those making special high-priced papers, such as hand-made paper.

Development of the paper machine was continuous during the nineteenth century. The basic principles of Donkin's machine were retained, but the size and the speed increased enormously. The latest newsprint machine is designed to run at 1,500 to 2,000 feet per minute, corresponding with an output of over 80,000 tons of paper per annum.

Waste Papers.—The re-use of old parchment was practised for centuries. Many of the records existing on vellum to-day are palimpsests, *i.e.* they have been used for writing upon more than once, the earlier script having been removed and the surface cleaned effectively. In the case of paper, however, it is easier to repulp the waste paper and to remake it into a new sheet. The chief disadvantage is that, owing to ink and dirt, the new paper has not usually so good a colour as the original, and on that account it is frequently used for wrapping paper and for boards for book-binding, etc. Waste papers, however, are not a good raw material for wrappings, as the fibres have usually been shortened and weakened. Boards, on the other hand, are thicker, and in such cases waste papers are a cheap and suitable starting-point. In the course of time the uses of boards have extended to industrial, scientific, electrical and building purposes. In some cases the use of new pulp (such as that from wood or jute) was justified, but the largest demand has developed mainly during the last fifty years for boards for cartons and general packing.

Formerly the mills produced boards discontinuously, in sheets on single cylinder or vat machines (Chapter X), but the installation of large multi-vat cylinder machines making a continuous web increased the output of carton and similar boards, leaving the single-vat mills to make specialties such as Jacquard cards, stiffeners, leather boards, millboards, press boards, etc. The result was an increased demand for waste papers, which reached its maximum during the 1939–45 war, when it coincided with the restrictions on the imports of wood pulps and esparto. Waste papers had therefore to help out the meagre supplies of raw material for printing and writing papers. The normal supplies from the waste-paper merchants were quite inadequate to satisfy the demand. The result was a national campaign to collect every scrap of recoverable waste paper, and mainly through the voluntary efforts of the public, nearly a million tons were collected during 1942. In 1938 the output of boards had already reached nearly 500,000 tons, and before the end of the war it had probably mounted to 750,000 tons per annum. Unfortunately the collection of waste paper in small quantities does not pay the collector, and to-day a large proportion of old paper is again being destroyed. During a period of economic difficulty such as the present, wastage of any kind is to be condemned and every effort should be made to recover not only all paper and rags but usable fibrous material of all kinds.

Another striking feature of British industry has been the development of coated papers and boards. Paper was first coated by machine about eighty-five years ago, but the modern mechanical developments of the last thirty years correspond with the great increase in lithographic, letter-press and photogravure printing. This highly specialised industry now performs an important function in the British home and export trade. It also proved of great assistance during the 1939–45 war in producing waterproof packaging and other specialty papers. Until recently all coating was an "after-operation" on the paper after its removal from the paper machine, but in recent years coating on the paper machine has yielded a cheaper second-quality coated paper for printing purposes (see Chapters X and XI).

The importance of paper and board making as one of the national industries is apparent on consideration of the number of persons employed. In 1938 there were over 66,800 engaged on the production side. Paper conversion (including box- and bag-making and the production of stationery) accounted for about 73,000, wallpaper 7,500 and printing and publishing another 287,000. The ancillary industries such as coal, china clay, chemicals, engineering would account for a total of about half a million.

A feature of recent years has been the tendency for co-operation between paper makers. Five centuries ago strict precautions were maintained to prevent spread of the knowledge of paper making. Even twenty-five years ago there was the feeling that some paper makers had secrets which enabled them to produce material beyond the scope of others. Now it is widely realised that there is little that need be treated as confidential, that ordinary recipes and formulae are matters of general paper making knowledge, and that the assets of a firm consist rather in the experience and skill of its workers. The trend towards co-operation is shown by the desire of paper makers to group together to discuss their technical problems, a desire which is evident from the activities of the Technical Section of the Paper Makers' Association of Great Britain and Ireland since its formation in 1920 (see also Chapter XII). The trend, especially during the last twenty years, towards the amalgamation of mills into groups controlled by a common directorate has led to increased collaboration between the technical staffs of the mills concerned.

Another event of major importance in the technical history of paper making in this country was the formation, in 1945, of the British Paper and Board Industry Research Association. The financial support for the Association is provided jointly by some 200 mills comprising the Paper Makers' Association and the Associations of Makers of Coated Papers, and out of public funds administered by the Department of Scientific and Industrial Research. The Research Association is well equipped with laboratories and apparatus, and an ambitious scheme of work covering every aspect of the industry has been drawn up with the advice of representatives of member mills. Mention should also be made of the Printing, Packaging and Allied Trades Research Association, which was founded originally in 1931; it deals with the finished paper in so far as it is used for printing and packaging. This too is supported jointly by industry and the Department, and it has a number of paper mills among its members.

CHAPTER II

THE NATURE AND USES OF PAPER

THE CONCISE OXFORD DICTIONARY defines paper as "a substance used for writing, printing, drawing, wrapping up parcels, etc., made up of interlaced fibres of rags, straw, wood, etc." The purposes and materials covered by the two "etc." are multitudinous. The definition, despite certain other limitations, does, however, make clear an essential characteristic of paper, namely, that it is a network—one might almost say that paper consists of a large number of holes enclosed by fibres. Such a definition would not really be facetious, for we shall see later that the holes in the sheet of paper play as important a part in determining its properties as do the physical and chemical characteristics of the fibres themselves.

The basic material of paper is [illegible]. This is a chemical compound which has been extensively studied during the past few years, and a great variety of useful substances has been obtained from it. These, however, are not of direct interest to the paper maker; he is concerned instead with the cellulose fibres which occur naturally in many vegetable tissues, from which they may be extracted fairly easily by mechanical or chemical means. There are many possible sources of these fibres (see Chapter III), but the most important are wood, grass (in the form of esparto), straw, cotton and linen (from rags) and cordage. Of these, wood is by far the most important. Fibres suitable for paper making can be extracted from nearly all plants, but the yield is usually so low that extraction becomes uneconomic. Extraction methods are described in detail in Chapters IV and V, and it is necessary at this stage only to point out that, after extraction of the woody and resinous materials and other impurities, the remaining cellulose is obtained in the form of fairly long, strong, almost colourless and transparent fibres, possessing dimensions, shapes and surface markings characteristic of the plant from which they have been isolated (see Chapter III).

Structure of Paper

Papers vary so much in their properties (consider, for example, the difference between blottings and greaseproofs) that some thought must be given to the microscopical structure on which these variations depend. The physical and chemical properties of the fibres themselves are discussed in Chapter III, and it suffices to state here that, as a chemical substance, cellulose is rather inert—that is, it is not easily attacked by chemical reagents. It is for this reason that papers can be made which have a high degree of resistance to the deteriorating effects of light and air and which will remain unaffected by the solutions used in photography or by the inks used by the printer.

Cellulose fibres have the useful property of swelling when immersed in water. In the swollen state a suspension of the fibres in water can be deposited as a layer of pulp, and when the excess of water is squeezed out a coherent mass remains on drying. In other words, the fibres act as their own cement if they are soaked in water and allowed to dry in close contact with one another. Thus, if a suspension of cellulose fibres in water is poured on to a wire sieve, most of the water drains through, leaving a layer of fibres which cements itself together on drying to form a coherent sheet. On examination through a microscope, this sheet is seen to consist of a mass of fibres arranged in all directions, with numerous air spaces or channels between them.

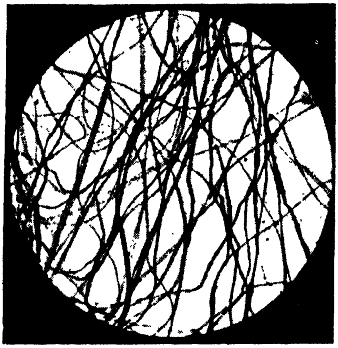

Fig. 3.—PHOTOMICROGRAPH OF THIN PAPER IN TRANSMITTED LIGHT.

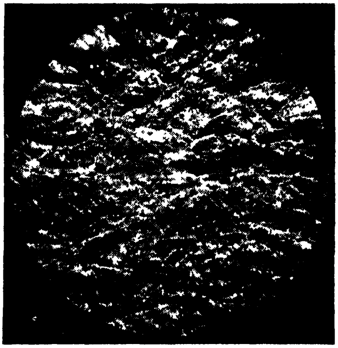

Fig. 4.—PHOTOMICROGRAPH OF RELATIVELY THICK PAPER IN REFLECTED LIGHT.

The thickness of the sheet depends upon the amount of pulp which is poured on the gauze in the first instance; and the size and arrangement of the channels depend partly upon the kind of fibres used, their origin, and the method of extraction, and partly upon the way in which they have been treated. The nature of this treatment is to a great extent controlled by the paper maker, who is thereby able to vary the properties of the finished sheet. The effect of soaking fibres in water is described in detail in Chapter VII, but their degree of swelling depends on the time they have been in contact with the water and on the amount and nature of the *beating* they have received. On continued beating in contact with water, the fibres swell more and more until eventually they lose most of their fibrous characteristics and become a jelly-like mass which, on drying out, gives a horny product having few of the characteristics of ordinary paper. We shall see shortly how the nature and degree of beating affect the properties of the product.

Fig. 3 is a photomicrograph of a very thin sheet of paper taken with a magnification of 50 diameters. Here the air spaces between individual fibres are quite clear. In thicker and denser sheets (Fig. 4) the fibres are more closely packed together and there are more of them, so that the porous, fibrous structure of the sheet cannot be so readily discerned. Nevertheless, it is still there, and is fundamental to the nature of paper, giving it properties which it is difficult to find in any other material. These properties include: a good mechanical strength combined with lightness and flexibility; porosity, and absorbency for liquids such as writing and printing inks; whiteness and, though the fibres themselves are appreciably transparent, opacity. For convenience, these properties may be grouped together as follows.

Mechanical Properties of Paper.—These depend, first, on the physical properties of the fibres themselves and, secondly, on the arrangement of these fibres within the sheet. Investigation has shown that single fibres have a remarkable strength and possess, when dry, a marked degree of elasticity, so that if bent or stretched within certain limits, they return wholly or partly to their original shape and length. Thus, Fig. 3 shows that the structure of the sheet resembles a very irregular, small-scale wire mattress. Fibres cross one another in all directions, and in general they adhere together more or less firmly at the points of contact. Some of the properties of the sheet may indeed be forecast by analogy with those of a wire mattress. First of all, the sheet will be light in weight, since a great part of the overall bulk consists of air spaces. Nevertheless, like the mattress, it is quite strong, especially towards tensile and bursting stresses; it is, however, less able to resist tearing stresses, since here the disrupting forces, instead of being distributed evenly through the sheet, are applied in succession to small groups of fibres which are separated from one another. Like the mattress, the sheet retains its shape, but possesses a high degree of flexibility, so that it can be rolled up and unrolled without damage; it can even be folded, if the folding is not overdone.

The mattress analogy is not perfect, however. In the ordinary mattress the wires are all in the same plane, whereas (except with very thin sheets which are only of single fibre thickness) the sheet of paper has a three-dimensional network structure, and may perhaps be regarded as a set of interlaced mattresses placed one on top of another. This three-dimensional network structure gives paper the valuable additional property of softness, so that when it is subjected to pressure (as in the printing press) the sheet is compressed slightly, regaining most of its original volume when the pressure is removed. This allows paper to take up the contour of printing surfaces much more closely than it would if it were hard or unyielding, and the transfer of smooth, even ink films is rendered easier.

The properties of the finished sheet depend on the kind of fibres used and their treatment during extraction and paper manufacture. If high mechanical strength is of importance, it is essential that the individual fibres should be damaged as little as possible by such treatment; they should also be as long as can be handled on the paper machine. Damage to fibres may be brought about either by chemical degradation or by mechanical "ill-treatment." Thus chemical degradation can occur if the fibres are over-bleached (see Chapter VI). Some reduction in strength is almost inevitable, and the paper maker has to effect a compromise between reasonable strength and reasonable whiteness; neither may be quite as good as he would like, but an improvement in the one is usually accompanied by a reduction in the other. Mechanical ill-treatment of the fibres may occur during beating (Chapter VII) if the fibres are cut more than is desirable; a strong sheet cannot then be expected.

Absorptive Properties of Paper.—If one end of a piece of clean, open, narrow-bore glass tubing is placed in a vessel of water, the water will rise a little way into the tubing so that the level inside is higher than that outside. This behaviour is characteristic of narrow tubes, and it is not confined to water; it is for this reason that a sponge holds large amounts of water. Since paper, like a sponge, has within it a large number of interconnected channels, one would expect it to behave in much the same way. The extent of the rise of liquid into narrow channels depends on the diameter of the channels, the material of which they are made, the cleanliness of the walls and the nature of the liquid. In general, the rise is the greater the narrower are the channels. If the walls of the glass tube are dirty or greasy, water rises in it less than it will if the walls are clean; yet if the tube is immersed in oil, grease on the walls makes little difference.

When a drop of liquid is placed on a sheet of unsized paper, it usually sinks in fairly quickly; it does not dry up by evaporation. What happens is that the liquid is drawn into the fine channels inside the paper. This fact is very important, since it governs the behaviour of inks on paper. If paper were non-porous, inks placed on its surface would have to dry either by evaporation or by chemical change, both comparatively slow processes. High-speed printing would then be difficult and excessive trouble would be experienced through smudging. As it is, however, the liquid portion of the ink (namely, water or oil) sinks rapidly into the pores of the paper, leaving a layer of comparatively dry, hard pigment on the surface, which allows the sheets to be stacked in contact without smudging.

If it is desired to produce as absorbent a paper as possible, such as blotting paper, it is essential to keep the channels in the paper open. This is done by avoiding the formation of fibre débris as much as possible during the beating process and by avoiding also any subsequent processes which tend to press together the fibres within the sheet. On the other hand, if the pulp is beaten very wet (Chapter VII) so that the fibres begin to lose their fibrous nature and become a shapeless jelly, and if the sheet made from them is compressed immediately after formation, the channels will be blocked up and the sheet will approximate to a solid mass, the result being a paper of the greaseproof type. In general, if all the channels are blocked up, the paper will be almost impervious to all fluids, even vapours and gases, unless they have a chemical action on the cellulose. If the channels are not blocked, the paper will let vapours and gases pass through it, but may or may not allow the passage of liquids. For example, a paper can be sized (Chapter VIII) so that it allows oils to pass through freely, but resists the passage of water to an extent depending on the degree of sizing. This is because the size has much the same effect on the cellulose fibres as the grease had on the glass tube, that is, it renders the surfaces less easily wetted by water. By judicious processing, therefore, the paper maker is able to produce wide variations in the absorbency of his sheet.

Optical Properties of Paper (such as whiteness and opacity) are due, again, to the fibrous structure of the sheet. Cellulose fibres themselves are more or less transparent; nevertheless, one can make a white, opaque sheet from them. The same effect is obtainable with clear glass, which when ground in a mortar produces a fine white powder. The effect is due entirely to the reflection and consequent scattering of light from a large number of small reflecting surfaces arranged in all possible directions. If a parallel beam of light falls on a sheet of white paper, it is broken up and scattered in all directions, like light passing through opal glass. The effect of this scattering is to make the paper appear opaque with a matt white surface. For the maximum whiteness and opacity, the scattering of light must be a maximum, and for the scattering to be a maximum the channels between the fibres must be small, numerous and filled only with air. If the passages are blocked or filled with a liquid which makes optical contact with the fibres, both opacity and whiteness are reduced. It is for this reason that paper which has been oiled or waxed is always much duller and more transparent than is the untreated paper.

Principal Types of Paper

Having discussed the main properties of paper imposed on it by its fibrous structure, we can consider how the structure of the paper is altered by the paper maker in order to produce a desired combination of qualities. It will be found that it is frequently impossible to produce all the qualities which the ideal paper should have, and the skill of the paper maker is then directed towards making the most satisfactory compromise possible.

The simplest papers from the structural point of view are the *filter papers* and *blottings* (see above, p. 27), in the manufacture of which the main object is to produce an open, absorbent sheet and to avoid blocking the channels. The fibres should be clean and of good quality (preferably cotton) and the beating process restricted to a cutting action, without fibrillation (see Chapter VII). Mineral matter, woody impurities and fibre débris are excluded so far as possible, since they tend to block up the channels and make the sheet less absorbent. Any after-processes which tend to press the fibres together (and hence close the channels) are avoided.

The requirements for filter papers for chemical work are particularly exacting, since it is important that the sheet should be as chemically pure and as inert as possible, so that it will not give rise to any reactions which might interfere with chemical analysis; the fibres must therefore be very carefully purified, and the prepared sheets are often washed with acids to remove the last traces of mineral matter. An acid-washed paper leaves hardly any residue on ignition and, if the cellulose has not been attacked, it is the purest form commercially available. Filter papers intended for use with a vacuum pump sometimes receive a further treatment with nitric acid, which hardens the paper and causes an appreciable contraction so that the sheet is better able to withstand the suction of the pump. The mean diameter of the channels in filter paper must also be controlled by the manufacturer, and various grades of papers are obtainable accordingly. With blottings, the main object is to produce a soft, bulky paper which will absorb liquid as rapidly as possible. Blottings are frequently dyed, but they do not ordinarily contain other non-cellulose materials. Soft-sized *duplicating papers* are in a similar category, but the standards of bulk and absorbency required are lower than for blottings.

A good quality *drawing paper* must be strong, permanent, white and opaque, take Indian and writing inks well, accept colour wash without mottle, and withstand the action of india-rubber or an erasing knife. The best drawing papers are still hand-made rag papers, but these are costly, and machine-made papers from rag or rag–chemical-wood mixtures are satisfactory for many purposes and decidedly cheaper. The necessary opacity is obtained by increasing the thickness, since the weight of the sheet is of minor importance. Beating is sufficient to ensure good felting together of the fibres.

Three surfaces of such papers are commonly available, namely, "not" (not hot pressed), "hot pressed" and "rough." The "not" surface is the natural finish of the sheet as given by the top layer of fibres; with hand-made papers it has a highly characteristic *grain*, and is much favoured by water colour artists. It is rather too rough for pen-and-ink drawings, however, and for these the "hot pressed" variety is usually preferred. To produce this, the slightly damp "not" paper is pressed between polished plates (see plate glazing, Chapter XI). The top layers of fibres are compressed to conform to the surfaces of the metal plates, and the result is a paper of appreciably smoother surface and slight gloss. However, the brightness and opacity of the paper suffer to some extent. Hot-pressed paper always appears slightly translucent by comparison with the corresponding "not" paper, because the fibres are pressed together. The third surface ("rough" or "antique") is similar to the "not" surface, except that the granulations are larger and more noticeable; it is favoured mostly by water colourists who work on a a large scale.

One of the drawbacks of a machine-made paper for water colour work is that the paper, when damped, tends to cockle up into a series of parallel ridges. This makes the application of uniform washes very difficult, even when the paper is stretched. A good hand-made paper, on the other hand, altnough it tends to bulge outwards and become loose on the drawing-board, does not form ridges, and stretching will eliminate cockling almost completely.

Unless a drawing paper is sized (preferably tub-sized, see Chapter XI), it will behave like blotting paper; pen strokes will have fuzzy edges (*feathering*) and washes will sink rapidly into the paper and appear patchy. In tub-sizing a skin of gelatin is formed on the paper surface. This improves the strength and finish of the sheet, makes it resistant to writing inks, and retards the penetration of water so that even washes of colour may be applied. The layer of gelatin filters out the colouring matter of writing inks, allowing the watery portion to pass through, so that ink lines remain sharp and feathering is prevented.

Cheaper drawing papers made by machine, often from wood pulp, are known as *cartridge papers.* They are usually yellower in colour and less permanent than are the best rag papers; nevertheless, they are satisfactory for many purposes. They are supplied in several different surfaces, and are usually hot pressed or calendered and invariably sized. The cheaper grades are not tub-sized with gelatin, but are engine-sized with rosin in the beater (see Chapter VIII). The rosin acts on the cellulose fibres rather like grease on the walls of a glass tube, so that the penetration of watery liquid is retarded and writing inks do not feather.

Writing papers are made in many different grades, sizes and weights. The requirements are similar to those for drawing papers, but are less stringent because extreme permanence is not usually necessary and the sheet is not normally damped. On the other hand, a good appearance, finish, surface and freedom from feathering are essential. The better quality writing papers are usually made from good grade rags or from chemical wood pulp (Chapter V) with or without rag or esparto; moderately beaten; dyed if necessary (for instance, ledgers); and tub-sized. The cheaper grades of writing papers may be made from pulps ranging in quality down even to engine-sized newsprint (see p. 32). High opacity and brightness are often of secondary importance, since many writing papers are tinted in any case (which lowers the brightness) and it is not often necessary to write on both sides of the sheet.

Printing Papers.—These are intended mainly for printing with oil-base inks. They are almost invariably machine-made papers (except possibly for special limited editions) containing wood pulp, alone or with esparto, straw, or occasionally rag. Sizing is not necessary for papers intended only for printing with oil-base inks, but if there is any likelihood that the paper will be written on with pen and ink (for instance, forms) it is better to engine-size the paper. Good opacity is of considerable importance, since such papers are usually printed on both sides, and the appearance of printed matter from the opposite side of the sheet (*strike-through*) can be very objectionable. The thickness of such papers cannot be increased beyond certain limits, since the bulk and weight of the book would become excessive; and the opacity is therefore increased by adding a filler to the pulp (Chapter VIII). The small particles of filler help to scatter the light falling on the sheet, and so improve its colour and opacity; they tend, moreover, to improve the surface of the paper and to make it more absorbent towards printing ink. Loading, however, always reduces strength, and too much of it produces a dusty, unsatisfactory paper.

Book papers vary considerably according to the class of book involved. The better grades are usually made from good quality chemical wood mixed with esparto or even rag, but cheaper productions demand cheaper papers consisting largely of the lower grade mechanical wood pulp (Chapter V). Printing papers containing appreciable quantities of mechanical pulp are inferior in colour, finish and strength to those made entirely from chemical wood (known as *wood-free* or *pure*) but they are cheaper.

The surfaces of both pure and mechanical printings vary greatly according to the purpose for which the paper is required. If a book consists mainly of type matter with a few line illustrations, a fairly rough surface may be quite satisfactory. Such a finish is that of the paper as it leaves the paper machine, and is known as *machine finish* (abbreviated, M/F). Such papers are easy to read by artificial light because of the absence of surface reflections; on the other hand, the rough surface does not give good results with rigid half-tone blocks, particularly when a fine screen has been used. Paper to be used with such blocks is therefore damped and calendered by passing it through stacks of smooth hot rollers under pressure; this "irons" the surface of the paper and renders it smoother. Unfortunately, however, the brightness of the paper suffers to some extent, and the paper becomes less absorbent. By adjusting the pressure of the rollers, a wide range of *supercalendered* (abbreviated, S/C) papers may be made, namely from little more than a M/F surface up to a decidedly glossy finish.

However, even the most highly supercalendered papers are not really suitable for half-tone reproductions of the highest quality, and for such work *art papers* are used. These consist (Chapter XI) of a *body* (or *base*) paper (preferably of esparto) to which a surface coating of mineral matter mixed with adhesive is applied, in such a thickness that the fibres of the body paper do not show on the surface at all. The paper fibres are therefore a support for the mineral coating. These art papers are usually supercalendered and give very good results with half-tone blocks. They are widely used, but are rather expensive, the surface is relatively easily damaged, and some persons object to their feel.

A cheaper paper having a similar surface (*imitation art paper*) is made by adding a large quantity of mineral loading to the pulp in the beater; the resulting paper is water-finished (see Chapter X) or damped and supercalendered, the result being a paper decidedly inferior to a good-quality coated art paper from the point of view of appearance and finish, but sufficiently smooth to give reasonably good results with fine screen half-tone blocks. In the more recent *machine-coated paper* the base paper is coated on the actual paper machine by rollers carrying a mixture of adhesive and mineral matter; these are usually inserted near the end of the drying cylinder system. The best of these machine-coated papers have a surface which is not markedly inferior to that of a second-grade art paper, and they are appreciably cheaper as they can be made at high speeds and from body papers containing mechanical wood.

Cheapness is of paramount importance with papers for newspaper printing (*newsprints*). Permanence is unnecessary, but the printed matter must be clearly legible and half-tone illustrations recognisable. Newsprints are therefore made from mechanical wood pulp containing sufficient (usually about 20 per cent.) chemical wood pulp to give the sheet the necessary strength. During the war repulped waste paper was largely used. Most newsprints are now unsized, but they may contain small amounts of filling or of colouring matter which gives the newspaper in which they are used a characteristic, easily recognisable colour. Their surfaces vary, but they are usually supercalendered to some extent to make as suitable a sheet as possible for half-tone reproductions.

Wrapping papers exist in many grades. Here colour and surface finish are of secondary importance, and the main requirements are that the paper should be strong and that it should provide some protection to wrapped goods especially in rain. This protection is achieved mainly by engine-sizing. The fibres should be long, strong and beaten so as to give a sheet having the maximum strength. Bleaching is avoided, since it tends to reduce strength and is normally unnecessary for such papers, and strong, brown kraft pulp is widely used. Brown wrapping papers are frequently *machine glazed* (abbreviated, M/G) by allowing them to dry with one side in contact with a polished, heated cylinder, much as a photographer glazes his prints. The side in contact with the heated cylinder receives a bright glossy finish, whilst the other side remains rough. M/G papers are useful for paper bags; the high gloss of one side makes it easier to print, and the roughness of the other provides a key for the adhesive used.

Light-weight tissues, made from chemical wood pulp, are frequently used for inside wrappings on packings. They are often highly coloured, though permanence of colour and strength are of no importance, as their main function is to fill up odd spaces in containers (packings) and so to protect the enclosed goods in transit. *Glazed imitation parchment* (G.I.P.) is a thin wrapping made from strong sulphite wood and having a wild look-through; it is heavily glazed, and engine-sized. Sometimes engine-sizing will not give the necessary degree of protection. In such cases papers may be passed through a bath of molten wax. Such *waxed* papers are resistant to the passage of water and even of water vapour (such as the moisture contained in the air on damp days), but their resistance is greatly impaired by folding, which breaks the wax film.

The satisfactory performance of papers of the *greaseproof* type depends on the extent to which the pores have been closed. This is done by beating the fibres to a much greater extent than is necessary (or desirable) for most other papers, so that the pulp approaches the jelly stage. Papers made from such pulp (especially if pressed or calendered at some stage after manufacture) have comparatively few interconnecting pores between the fibres, so that the passage of liquids is difficult. However, they are not strictly "greaseproof," for oils and fats will penetrate them after a sufficient interval of time; nevertheless, they resist the penetration of butter and similar fatty foods for a reasonable period and they are often used for wrapping these commodities.

If a good greaseproof paper is well damped and supercalendered, the gelatinous cellulose is pressed together to a compact mass, so that the gaps between fibres are reduced to a minimum, and the result is an almost transparent sheet of very low porosity, known as a *glassine*. Such papers are very useful as higher-grade wrappings and for window envelopes, book covers, etc. There is, however, a different type of paper of low porosity known as *vegetable parchment*, which is made by passing a sheet of paper through a bath of strong sulphuric acid. The acid gelatinises part of the cellulose on the surface, and when the sheet is next passed through a trough of water, the gelatinised cellulose is re-deposited between the fibres so that it tends to fill the gaps between them and form a continuous surface film. The manufacture of good vegetable parchment papers depends on the strength of acid and the time of immersion, because if the dissolution of the cellulose by the acid proceeds too far, the sheet will be ruined. Vegetable parchment papers are very resistant to grease on account of their low porosity and they have a high strength in the wet state. They have also a higher water resistance than has a greaseproof paper, but are rather more expensive.

Specialty Papers.—This chapter would not be complete without brief mention of some of the papers which have been developed for specific purposes, and notably for the Services during the 1939–45 war. For example, *wet-strength papers*, which retain an appreciable percentage of their mechanical strength after soaking in water, are made by the addition of a urea-formaldehyde or melamine-formaldehyde resin to the pulp during the manufacture of the paper. The resin cements the fibres together, and the bond tends to improve with age. The advantages of printing maps on, or making certain wrappings from wet-strength papers are obvious. The war has also seen the production of large quantities of *bitumen laminated* or *bitumen impregnated paper* for outer wrappers. Such papers when well made are impervious to liquid water, and have been extensively used as the inner liners of packing cases for goods to withstand unfavourable conditions of climate and transport. They are made from two layers of stout, sized kraft paper, between which is a layer of bitumen to act as the water-resistant barrier (*union kraft*). More recently, they have also been made with the bitumen not as a separate layer, but interspersed between the fibres so as to coat them and fill up the spaces between them. Such papers give very satisfactory results.

Security papers are used for cheque forms and similar documents, the writing on which is liable to be tampered with either by erasure or by the application of a chemical ink remover. Naturally, little information about them is available. Most of them are not fully sized and have a surface which readily comes away if it is scraped with a knife or wetted with an ink remover. In addition, some contain chemicals which change in colour when an ink remover is applied, leaving a characteristic stain. Forgery is thus made considerably more difficult.

The requirements for *cigarette papers* are rather exacting. The paper must have no characteristic smell or taste on burning, and it must be thin but opaque, since the appearance of the cigarette suffers if the tobacco shows through the covering to any marked extent. Opacity is usually secured by the addition of a filler such as calcium carbonate, which gives a good white appearance and helps to promote uniform burning of the paper. *Bible paper* (or *India paper*) and *air-mail paper* are other examples of papers which must be thin and yet have good opacity.

Miscellaneous.—The war resulted in a great increase in the use of paper products. Large quantities of paper and board were used in the manufacture of waterproof tubes for ammunition containers and the like. By the addition of synthetic resin, paper can be made into articles remarkable for their lightness combined with high mechanical strength; a good example is the jettison petrol tank carried by fighter planes on long-distance operations.

Insulating papers for the electrical industry range from thin condenser papers to coverings for telephone and power transmission cables. Wallpapers and poster papers were responsible for a considerable tonnage until the war restricted supplies of pulp. Boards for cartons and many other purposes are in continually increasing demand. Tissues are used for wadding and surgical dressings, transfers, stencils, and (especially in America) for handkerchiefs and towels. The plastics industry makes use of paper as reinforcement in laminated sheets.

To give full details of all the papers made for every special purpose would extend this chapter unduly, and for further information reference must be made to the Reading List on p. 193. It is difficult to forecast what future developments are likely, but it is certain that we have not yet reached the limits of the applications of paper.

CHAPTER III

THE FIBROUS MATERIALS OF PAPER MAKING

THE FIBROUS raw materials for paper making are derived almost exclusively from plants, of which there are thousands of different species in the vegetable kingdom, ranging from common grasses to the largest trees. The great majority are capable of yielding a usable fibre; nevertheless the number of species economically suitable as sources of fibre for paper making is relatively limited.

Cellular Structure of Plants.—Much of the structural portion of the flowering plant is composed of complex tissues of (frequently hollow) cells. These cells are often too small to be visible to the naked eye, but in general they have a simple shape. Their walls are composed essentially of a substance known as *cellulose,* a chemical compound of the elements carbon, hydrogen and oxygen, which is built up (or synthesised) by the plant during its growth. Closely associated with this cellulose, and contained in the body of the cell wall, are varying proportions of non-cellulosic substances. The more important of these are *lignin,* occurring in wood and jute, for example; and *pectins,* substances allied to cellulose, occurring for example in flax, esparto, and straw. In addition there may be in these tissues such minor constituents as tannins, resins, waxes and mineral substances.

Those plant cells which resemble minute threads in shape, the length being many times greater than the breadth, are known as *fibres.* These form the "bones" or "skeleton" of the plant and contribute largely to its mechanical rigidity. In the plant they are grouped closely together, sometimes in separate bundles (known as *fibro-vascular bundles*) distributed longitudinally in the interior of the plant stem or leaf and surrounded by a tissue of non-fibrous cells, as, for example, in straws and grasses. Sometimes, however, the fibres are grouped in the form of a closed ring situated just below the surface of the stem; these are the *bast fibres,* and the linen fibre from the flax plant is a good example. Again, the fibrous tissue may be arranged in roughly concentric rings to form practically the whole of the plant stem, for instance, as in trees.

In a very few cases the fibres grow freely in the form of a hairy covering on seeds; the cotton fibre is the only important example of this type.

On the basis of their location in the plant, fibres used as raw materials for paper making may be classified roughly as follows:

Seed hairs—cotton.
Bast fibres—flax, hemp, jute, ramie.
Wood fibres—coniferous and deciduous woods.
Leaf fibres—esparto, manila, sisal.
Grass—straw, bamboo, bagasse, maize stalks (esparto is sometimes included in this class).

Properties of Fibres

The seed hairs contain the highest proportion of pure cellulose and require the minimum amount of preparatory chemical treatment to yield a product suitable for paper making. The fibres in the remaining classes are poorer in cellulose and require chemical treatment of greater severity. The above fibres differ in character and size from plant to plant, and even in plants of the same family the fibres, though similar in appearance, are by no means identical in size. This point should be borne in mind when studying the dimensions given below for the various paper-making fibres. These are average values, and individual fibres may be much smaller or larger. All vegetable paper-making fibres, however, are tubular in form with an overall diameter of 0·01 to 0·05 millimetre, and are usually closed at both ends. In length they range from 1·25 mm. or less, to 25 mm. or more. [*Note* : 1 millimetre (mm.) equals approximately 1/25 inch.]

In all cases these fibres are adapted to the particular function they have to perform during the life of the plant, and it is for this reason that they show such diversity in size and in the thickness and composition of their walls. The different plant fibres have their own special characteristics, and these contribute directly to the quality and type of paper that can be made from them.

When subjected to bruising or crushing in the presence of water, the cellulosic fibre wall becomes increasingly retentive towards water, and in addition it may be split or gradually broken up into extremely minute *fibrillae*. This is one of the effects brought about by *beating* (see Chapter VII). Fibres in this condition when deposited from a water suspension and then allowed to dry, form a compact mass (a sheet of paper) in which they are bonded together by reason of their gelatinised and fibrillated surfaces. In general, the longer the fibres, the more gelatinous their surface and, up to a point, the greater their degree of fibrillation, the stronger will be the resulting sheet. Individual fibres have remarkably high tensile strengths, and when a sheet of paper is torn the fibres themselves are seldom fractured to any great extent; it is rather the bond between fibre and fibre that breaks down. This bond between fibre and fibre in dry paper, however, is very drastically loosened by water, so that a wet sheet of paper has a greatly reduced strength compared with a dry sheet. When beaten in water the surfaces of animal fibres such as wool and silk are not gelatinised or fibrillated, and in consequence a coherent sheet of paper cannot be made from them.

Fibrous Cellulose, the basic substance of the paper-making fibre, is soft, flexible, white (when pure) and insoluble in all the simple solvents such as water, alcohol, petrol, etc. Chemically it is remarkably inert, and it has good resistance to dilute alkalis and, for short periods and at low temperatures, to dilute acids. If, however, traces of free acid are allowed to remain in a sheet of paper, the cellulose gradually becomes degraded and the strength of the individual fibres is so reduced that in time the sheet falls to pieces. Cellulose can, however, be dissolved in solutions of zinc chloride, ammoniacal copper oxide, or strong sulphuric acid, from which it can be recovered by suitable means in a gelatinous condition. Use is made of these properties in the production of *vulcanised boards*, *Willesden goods* and *waterproof papers*, and *vegetable parchment*, respectively (see Chapter II).

While it is true to say that fibrous cellulose could be produced in the laboratory from any flowering plant, there are numerous factors which limit the actual selection of a paper-making raw material. Thus, the fibre itself must be of suitable size and character, the plant from which it grows must be plentiful, and continuity of supply must be assured. The collection of the plant must be convenient to carry out, and the location should be close to the paper mill or pulp mill so as to reduce transport costs as much as possible. If the plant does not have to be cultivated, this usually reduces costs still further. The fibre must also be capable of being isolated from the plant by processes that do not entail too difficult or costly a technical operation. There is also always the possibility that new sources of paper-making fibre will be developed in the future, as economic conditions change and new technical advances are made.

Finally, when choosing the fibres for producing a certain paper, the paper maker has to consider what properties are demanded from the paper and what limitations exist in the matter of the price of the finished article. For this reason mixed fibre furnishes are frequently used.

The longer and stronger fibres used for paper making, such as cotton, linen and hemp, are of greater value to the textile manufacturer, who in these circumstances has first call on them; the paper maker, therefore, then has to rely largely on textile rejects and worn textiles (rags) as his source of fibre.

Cotton (Fig. 5).—The cotton fibre, which is the purest form of natural cellulose available to the paper maker, is a seed hair from the cotton plant, an annual shrub of the same family as the common mallow. It grows in sub-tropical, warm, damp climates, to a height of from 4 to 6 feet. The plant is cultivated, and the bulk of the cotton of commerce is grown in North America (Southern States), Brazil, Egypt and India. The fibre itself grows in the form of slender hairs on the surface of the seeds contained within the seed pod. When the seed pod (or boll) is ripe, it bursts open and the seeds, together with their envelope of cotton hairs, are ready to be picked by hand.

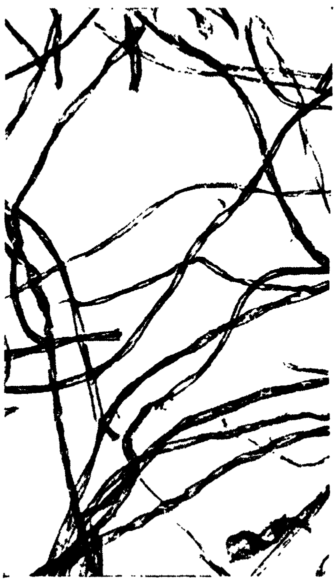

Fig. 5.—COTTON FIBRES (× 60).

The fibre is separated from the seed by means of machinery, the fibre being then spun into thread and the seeds crushed for the extraction of oil. Almost the whole of the world's production of raw cotton fibre is used in the manufacture of textiles or textile threads, and the paper maker therefore obtains his cotton fibre in the form of rejects from textile factories or as worn and discarded textiles. Only a small proportion of raw cotton (in the form of short-fibred *linters*) finds its way direct to the paper mill. Thus cotton rags are the chief source of cotton for paper making, and in grade and quality they vary from new "white cuttings" down to heavily soiled, worn, coloured and tendered materials. In a broad sense each of these different qualities is specially suited for the production of a particular type of paper. It is, therefore, clear that the previous history of the rags used by the paper maker has a profound influence on their paper-making properties.

The ripe cotton fibre is a flattened, twisted tube, on an average 25–32 mm. long and 0·025 mm. wide. The cell wall consists of almost pure cellulose and is relatively thin, while the central canal (or *lumen*) within the fibre is about half the width of the fibre. The edges of the fibre are thickened, so that a cross-section resembles a dumb-bell in shape. The appearance of the raw fibre is similar to that of a piece of rubber tubing from which the air has been sucked out, and which has then been twisted lengthways.

As the original fibre consists of practically pure cellulose, the chemical treatment necessary to give a pure white fibre is relatively mild in nature. Consequently the cotton fibre is spared the drastic processing, with the danger of accompanying chemical attack on the cellulose itself, necessary for the liberation of certain other fibrous materials. The cotton fibre and paper made from it have, therefore, a high inherent durability.

When carefully beaten so as to fibrillate the fibres and yet preserve fibre length, cotton imparts high strength to a sheet, as is shown by banks, loans and bonds made from it. When beaten so as to cut the fibres and reduce fibre length, rather than to fibrillate, cotton (especially from well-worn and tendered rags) gives the highest qualities of blottings. Between these two limits almost every type of paper can be made by suitably regulating the beating process (see Chapter VII). Cotton, therefore, is an extremely versatile fibre and as such is of great value. It is expensive, however, and its use is thus limited to those papers which command an adequate price.

Owing to the twisted nature of the fibres, which can be largely preserved by careful beating, cotton is capable of imparting *bulk* and softness to paper; such twisted fibres cannot be packed together so closely in the paper sheet as a fibre of similar dimensions but free from twist. Further, owing to the irregular surface of the fibre and to its relatively loose packing in the sheet, certain papers made from cotton tend to have a high opacity.

Summarising, therefore, the most important properties imparted to paper by the cotton fibre (assuming the selection of suitable grades of rags and suitable beating treatment) are strength, softness, bulk, opacity, purity and durability, and where desired, absorbency.

Linen (Fig. 6).—The linen fibre is derived from the bast tissue of the stem of the flax plant, which is cultivated extensively in the United States of America, Russia, Hungary, France, Belgium and Ireland; these countries together produce most of the world's supply of flax. The plant itself is a small annual, growing to a height of about 3 feet, and having a slender stem. The bast tissue is just beneath the surface of the stem in the form of a closed ring, the fibre in the remaining cellular tissue of the stem being of no commercial value.

On maturity the plant is gathered, the leaves and seeds are removed, and the bare stems subjected to a process known as *retting* to loosen the non-fibrous elements. This involves simply immersion of the stems (tied together in bundles) in stagnant water; fermentation ensues and, in a few days, the whole structure of the stem is so loosened that the long filaments, or coherent bundles of bast fibres, can be readily separated from the unwanted tissues by a mechanical process (*scutching*). The actual yield of dried bast fibres obtainable is only about 5 per cent. of the weight of the original, living flax plant.

The fibre is used largely for the manufacture of spun threads and textiles, so that, as with cotton, the paper maker obtains most of his linen fibre in the form of rejects from the textile factories and as worn or discarded textiles. A certain amount of flax waste or tow, too short in fibre length for spinning, is also directly available to the paper maker. As with cotton, these different sources of flax vary in their properties as raw materials for paper making. The linen fibre, however, is much stronger than that of cotton. The ultimate linen fibre has a rounded section and tubular shape, with thick walls and a narrow central canal, the average dimensions being about 25 mm. length and 0·02 mm. diameter. The fibre is pointed at both ends and has numerous cross-markings and thickened areas along its length. The fibre surface is smooth and sometimes has longitudinal striations. Like all bast fibres, on beating it is relatively easily split longitudinally into fine fibrillae, particularly at the ends; so that the ends of beaten fibres frequently have a brush-like appearance. This fibrillation, together with the comparatively great length of the fibre, accounts largely for the great strength of paper made from linen. Under the action of the beater roll pulp from linen fibres is easily "wetted," and readily becomes almost gelatinous and very retentive towards water. The beaten pulp does not easily part with its water on the machine wire, and the stuff is thus *wet*. In consequence it is difficult to make a paper of heavy substance from linen. Further, owing to the great thickness of the fibre wall, the linen fibre stands up extremely well to the action of the beater roll, and it is not difficult to preserve the fibre length.

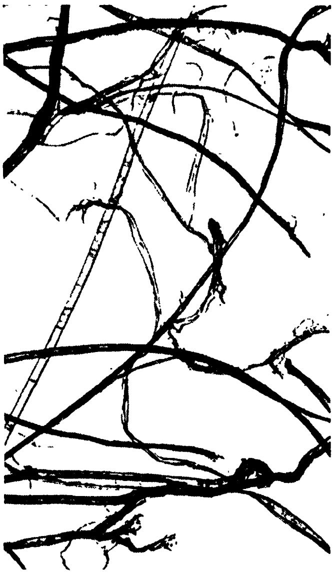

Fig. 6.—Linen Fibres (× 60).

When carefully prepared and bleached, linen is a pure form of cellulose and is very durable. However, because of its high cost it can be used only for the highest qualities of paper, and even then it is seldom used alone but is mixed with other fibres such as cotton and wood pulp. When used alone, it is limited to certain thin, strong papers such as banknote paper. It blends well with other fibres, and is so used to impart additional strength to the sheet. The most valuable properties given by linen fibre to a paper are strength, toughness, durability, and a pre-eminent impression of quality.

Wood Pulp, in one form or another, is the most widely used of all fibrous raw materials for paper. In contrast with the position in the case of textile fibres, the paper maker never uses timber which has already been employed for other purposes though wood waste from the lumber industry is occasionally raw material for pulp manufacture (see Chapter IV). There are two entirely different classes of wood pulp, namely mechanical pulp and chemical pulp, and they are dealt with in detail in Chapter V. Each can be sub-divided according to the process used for manufacture. The mechanical pulp is made by grinding wood logs on a grindstone under a stream of water, so that the resulting pulp contains much fibre débris together with bunches of fibre fragments. The chemical processes, on the other hand, depend on the use of solutions to dissolve away the encrusting substances which cement the fibres together in their natural state. In this way the fibres are separated with minimum physical damage and are mostly whole.

Wood for pulping is obtained from either *coniferous* or *deciduous* trees, and chiefly from the former. Of the coniferous (cone-bearing) trees the spruces are the most important, though the pines are used in certain processes. Deciduous trees shed their leaves in winter; those used are mainly poplar (aspen), chestnut, eucalyptus, beech and birch, but they account for a comparatively small proportion of the pulp made. The growth of a tree takes place almost entirely during the spring and the summer; only when the early autumn weather is unusually mild are fibres formed in that season. The characteristics of the fibres formed change gradually throughout these seasons. Thus in the spring the fibres are wide and thin-walled, whilst those formed during the summer are smaller in diameter but have thicker walls. These differences account for the annual rings visible on the cross-section of a log. With most timbers radial lines (*medullary rays*) are also visible.

Spruce (Fig. 7).—The fibres of Norway spruce (*Picea excelsa*) are 3–4 mm. long. Those formed during the spring have a diameter of 0·025–0·030 mm. and, being thin-walled, they are readily flattened and appear under the microscope like thin ribbons. In the cell wall are groups of *pores*, each having a surrounding "halo," the appearance of which depends on the severity of the pulping treatment used. In drastically treated pulp they may be almost obliterated, whilst mild treatment leaves them clearly defined. On the other hand, the fibres formed during the late summer appear tubular under the microscope and lack both pores and haloes.

Pine.—The fibres from Scotch pine (*Pinus sylvestris*) are very similar microscopically to those from spruce, but the spring fibres often have (in addition to pores and haloes) groups of 2 to 8 wide openings in the cell wall. When they are visible they serve to distinguish pulps made from pine and spruce. Other coniferous woods yield similar fibres, though slight differences may be found in the shape and arrangement of the pores in the spring fibres; thus in some cases they are eye-shaped and very numerous.

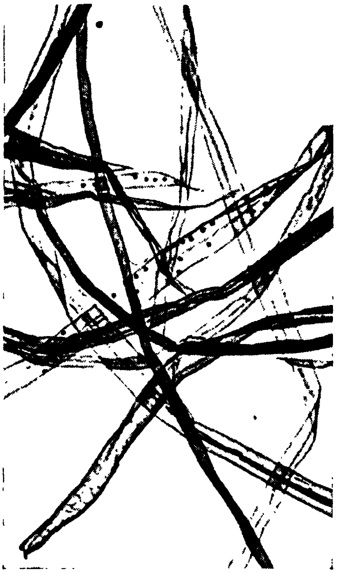

Fig. 7.—Spruce Wood Fibres (× 100).

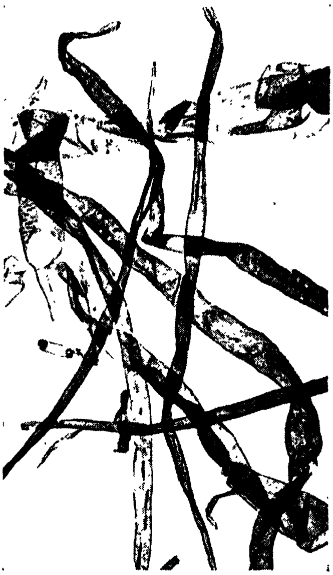

Fig. 8.—Deciduous Wood Fibres (× 100).

Deciduous Woods yield fibres which are shorter than those from coniferous trees; thus poplar fibres are about 1·5 mm. long, while eucalyptus fibres are slightly over 1 mm. long. There is little difference between the spring and the summer woods, but there are also present numerous characteristic thin-walled vessels, open at the ends and occasionally perforated with rows of holes (see Fig. 8).

Mechanical Wood Pulp (Fig. 9) is usually made from spruce. As would be expected from the treatment of the wood, it is rare to find complete, undamaged fibres. On the other hand, much of the pulp consists of splinters of fibres with occasional clumps of broken fibre. The haloes surrounding the pores are clearly defined, and in addition there may be present remnants of the medullary rays, which appear under the microscope as bars crossing one or more fibres.

Properties of Wood Pulps.—It is apparent that mechanical pulp has limitations for paper making, although because it is cheap it is used extensively for newsprint and for the cheaper grades of wrappings and printings (see Chapter II). It cannot produce a strong or durable sheet of paper; and it cannot be properly fibrillated or "wetted" on beating and in consequence the cohesion of the paper web made from it is poor. Indeed, newsprint has to be fortified by the addition of at least 15 per cent. of strong sulphite wood pulp. Mechanical wood has, however, a high opacity—a very important property for newsprint.

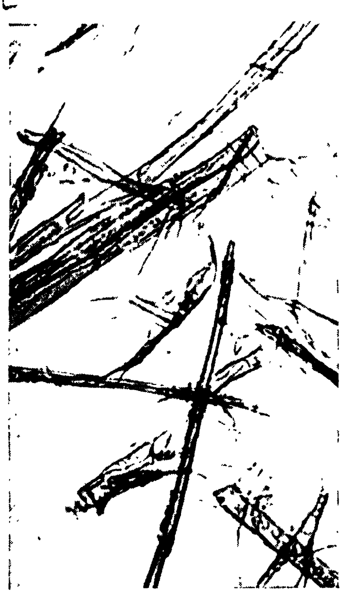

Fig. 9.—Mechanical Wood Fibres (× 100).

On the other hand, the fibre of chemical pulp from coniferous wood stands up well to the beater roll and is comparatively easily wetted. It does not fibrillate in the same manner or to the same extent as cotton or linen, but it can nevertheless be fibrillated to some degree. As it is initially much shorter in length than rag fibres, it must not be unduly shortened on beating if its full strength is to be retained.

When beaten for maximum strength sulphite (coniferous) wood pulp loses opacity; and as the fibre is relatively flat and packs closely, the resulting paper has a low bulk. Some of these pulps can be beaten to such an extent as to give a highly translucent sheet, as in the case of greaseproofs, glassines and natural tracing papers (see Chapter II).

Deciduous wood pulp, on the other hand, particularly when produced by the soda process, is more opaque and bulky, giving a well-closed sheet with a good surface. The superior bulking properties can be attributed partly to the more crinkled state of the fibre resulting from this method of digestion.

To sum up, the production of chemical wood pulp is a highly specialised study, and by choosing suitable woods and varying the cooking conditions in the three chemical processes used (see Chapter V), a range of pulps can be produced which used singly or as blends cover as wide a range of papers as can be produced from cotton. Within recent years much progress has been made in extending this range (particularly as regards highly purified pulps) and in improving the uniformity of quality of each grade. There is every reason to believe that further improvements of this nature can be expected.

Esparto (Fig. 10) has held a unique position in paper manufacture in this country ever since its introduction in 1861, and though unobtainable during the war of 1939–45 it is now in use again in large quantities as conditions have become more stabilised.

The source of this fibre is the leaf of esparto grass, which grows in southern Spain and in North Africa, the grass from the latter source being the lower in quality. The climate in these regions is hot and dry, and to minimise an excessive loss of water by transpiration the leaf blade curls round its axis in the form of a tube. The grass is wiry and tough, and as it is gathered by pulling (not cutting), it is liable to be contaminated with roots. The harvested grass is hand-picked to remove the coarser impurities, baled and shipped to this country in this state. Esparto grass is also used to make coarse ropes and mats. The true fibres are located in bundles within the leaf, and amount to over 45 per cent. of the air-dry weight of the raw grass. They are liberated by cooking the grass under pressure with caustic soda solution, after which it is easily broken down into pulp (see Chapter IV).

The actual fibre is short and fine, and has, in fact, the smallest diameter of all the common paper-making fibres. The average dimensions are 1·5 mm. length and 0·013 mm. diameter. It has a round section, with thick cell walls and a narrow central canal, and it is finely pointed at both ends. Accompanying the fibres there are in the pulp, as produced by digestion, numerous non-fibrous structures from the cellular tissue in which the true fibres are embedded in the natural leaf; these are small and have serrated edges. In addition, small pear-shaped hairs from the inner surface of the leaf (*trichromes*) are present. These non-fibrous constituents have no felting properties whatever, and because they are small they can be removed to a great extent without undue loss of fibre by carefully controlled washing in the breakers or bleaching potchers (see Chapters IV and VI). Nevertheless some are always retained, and their highly characteristic shapes serve to identify esparto pulp in the analysis of a paper *furnish* under the microscope.

As the fibre is naturally short it must be beaten so as to preserve the length, and in fact the mill beating of esparto consists primarily of brushing out clumps of fibres and of disintegrating portions of root or other incompletely digested particles (*shive*).

Surprisingly enough for a fibre of such small size, esparto is capable (when suitably beaten) of giving bulk and opacity to paper, and it is therefore used in the production of the so-called *featherweight* printing papers which were formerly such a feature of novels and children's books. As the fibre is small and flexible, it confers on paper a closeness of texture and smoothness of surface which are unique. Further, esparto papers expand rather less when wetted than do papers made from almost any other fibre. The combination of these factors renders esparto particularly suitable for the manufacture of printing papers, especially where multi-coloured printing makes good colour register essential. Esparto is also used for the *body paper* for coated papers and for good quality writings, especially those having a watermark, as it watermarks very clearly (see Chapter II). When tub-sized (see Chapter XI) such writing papers have a surprising strength, and owing to the smoothness of the sur-

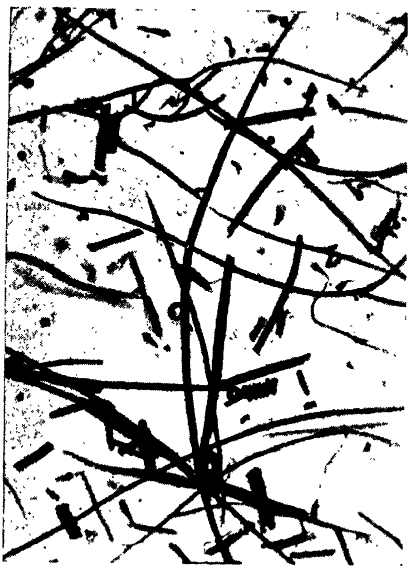

Fig. 10.—Esparto Fibres (× 100).

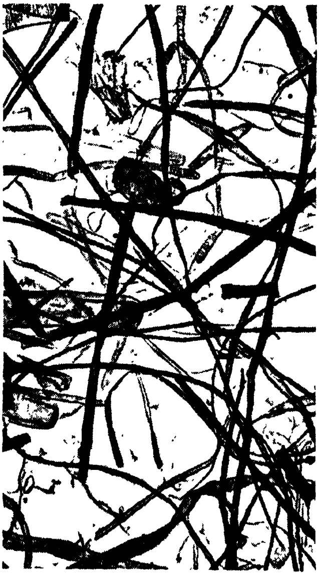

Fig. 11.—Straw Fibres (× 100).

face they are very easy to write upon. Owing to the shortness of the fibre, however, high resistance to tearing cannot be expected, and for this reason it is usual to add a proportion of longer and stronger fibre (such as wood pulp or rag) to the furnish. Moreover, these fibres reduce the tendency of esparto fibres to clump together into minute knots (*ricing*).

The advantageous properties conferred by esparto are thus: bulk, opacity, smoothness of surface, low expansion on wetting (*i.e.* flatness), and clear watermarking; the limitations are a certain lack of strength and durability, as compared with rag.

Straw fibres (Fig. 11) are obtained from the stems of various cereal plants such as wheat, oat, barley and rye, which are cultivated primarily for the grain they yield. These cereals are grown extensively in temperate climates, and the potential source of fibre for the paper maker is thus large. Before the recent war a very large proportion of the cereal straws in this country was utilised for agricultural and other purposes, and no use was made of the fibre as such. Owing to the severe limitations in the supplies of wood pulp and esparto grass during the war, the British paper industry was compelled to use considerable quantities of straw.

The fibres are located in separate bundles embedded in a mass of non-fibrous cellular tissue, and they comprise rather less than half the weight of the raw, air-dry straw. In order to isolate these fibres, digestion under pressure with solutions of caustic alkalis in water is necessary (see Chapter IV).

The straw fibre is tubular, pointed at both ends and has a fairly thick cell wall. It resembles the true fibre of deciduous woods, but it is somewhat longer and finer and has no surface markings. The average size is about 1·5 mm. long and 0·015 mm. in diameter. Straw pulp produced by alkaline digestion contains, in addition to the true fibres, many non-fibrous cells of widely differing shapes and sizes, but all very thin-walled. Some of these are very small, being much shorter than the true fibre; their presence is believed to cause straw to work *wet* on the machine wire, and this results in a dense, hard sheet, with relatively low opacity and a distinctive "rattle" on handling. Beating, therefore, must be carried out carefully, so as to preserve the fibre length as much as possible and to prevent the pulp becoming unmanageably wet on the machine wire. By suitably screening a suspension of straw pulp in water, the small cells can be separated fairly completely from the true fibres, but the yield of the latter is then much lower than the already low yield of crude pulp obtained before such treatment.

Straw may be used alone, but it is more frequently mixed with longer fibres, such as wood pulp or rag, and this blend finds wide application in the production of thin, hard writing (*bank* and *bond*) and other papers, although during the war its use was extended to printing and to many other papers for which it is less suitable than is wood pulp.

Straw is also cooked with lime, to produce a much cruder grade of brown pulp suitable for the manufacture of the well-known strawboards; in this case no attempt is made to isolate individual fibres.

Other Fibres

Hemp fibre (Fig. 12) is the bast tissue of an annual shrub grown extensively in India, Russia and America. The crude fibre, liberated by retting (see p. 40) contains about 75 per cent. of cellulose; it usually comes to the paper maker in the form of spinning waste, twine, cordage, ropes, etc.

Fig. 12.—Hemp Fibres (× 200).

The ultimate fibre is about 20 mm. long and 0·02 mm. in diameter; it is similar in appearance and behaviour on beating to linen, but has thick walls with longitudinal striations and transverse fissures. It can give an extremely strong and durable paper, and it is used for bank-notes, cigarette and other strong tissues, insulating and similar papers; the coarser grades are used for making strong wrappings.

Manila fibre (Fig. 13) occurs in the leaves of a plant of the plantain family, which grows in the Philippine Islands. The crude fibre contains about 65 per cent. of cellulose, and is used for making ropes.

The ultimate fibre is about 6 mm. long and 0·025 mm. in diameter. It is very even and regular, with relatively thin walls, and it gives an extremely tough, almost untearable sheet. It is used chiefly in the manufacture of stencil, insulating, envelope and wrapping papers, where great strength is required and a high white colour is not necessary.

Jute (Fig. 14) is the bast tissue of an annual plant grown in India. The fibre is isolated by retting and contains about 60 per cent. of cellulose; it is used for making coarse cloth and bagging. It comes to the paper maker in the form of the butt ends of the retted fibres and as used sacking.

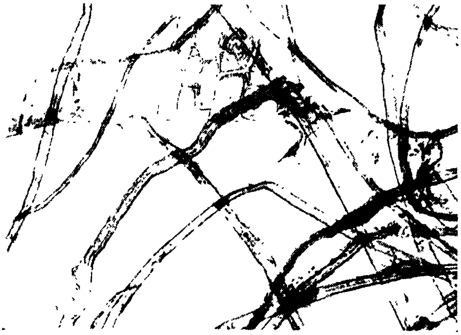

Fig. 13.—MANILA FIBRES (× 200).

The ultimate fibre is 2 mm. long and 0·02 mm. in diameter; it is smooth and has a central canal with a very variable diameter. Like other bast fibres, it fibrillates readily on beating, and when bleached gives bulky and opaque papers, similar in general character to those produced from esparto. It is also used in wrappings, specialty boards and to replace part of the hemp in cigarette tissues.

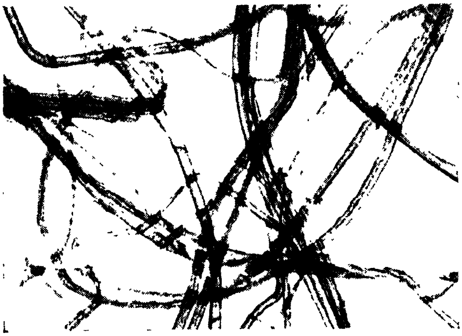

Fig. 14.—JUTE FIBRES (× 200).

Other paper-making fibres of interest include **bamboo**, which is widely used in India and is similar to straw in its microscopical characteristics and conditions for digestion; *bagasse*, the residue from the sugar cane after extraction of the sugar, which is used in America in packing papers and boards, and is also similar to straw in general characteristics; *ramie* (China grass), suitable for thin, strong papers, and having long fibres with rounded ends and striated markings; and *sisal hemp*, a fibre from the leaves of *Agave sisalana*, used for making rope and twine, in which form it comes to the maker of wrapping papers.

CHAPTER IV

PULPING METHODS—FIBRES OTHER THAN WOOD

Introduction

THE METHOD of preparation of a pulp from a fibrous raw material depends on both the nature of the raw material and on the type of paper required. Usually the operation consists essentially in separating the ultimate fibres, and then purifying them to an extent depending on the quality required of the final product. When the ultimate fibres of the raw material are long, say over 7 millimetres (as with cotton, linen or hemp), they can usually be shortened with advantage during their separation. On the other hand, if they are already short (less than 4 millimetres, as in wood, esparto and straw), care is taken to preserve the length, and any further shortening which may be needed is obtained by beating (Chapter VII).

Clearly, the nature of the purification is governed by the kind of impurities to be removed. These may consist of dust, foreign matter soluble in water, and colouring matters, as in rags. On the other hand, the impurities may be intimately associated with the cellulose in the form of rather indefinite compound celluloses, such as *ligno-cellulose* as in wood, or *pectocellulose* as in esparto and straw. Each type of impurity usually responds best to a particular form of treatment, and the aim of the pulp maker is to choose this so as to combine efficiency and economy.

Some of the purification may be accomplished in the dry state, such as the removal of dust from rags or of sand from straw, in a duster or willow. Other dirt may adhere so firmly that it is removable only with the aid of a detergent, possibly after disintegration of the material. Greasy substances will normally require treatment with hot alkali, and colouring matters may respond to bleaching. On the other hand, the compound celluloses require more drastic attack with alkali or other chemical agents, often at high temperatures.

The kind of product required must always be borne in mind. Thus in the manufacture from low-grade rags of felt for impregnation and use as roof coverings, all the purification needed is the removal of coarse *contraries* (such as sand, and pieces of metal and wood). Again, in the production of newsprint the essential quality is cheapness, and there is no necessity to remove the lignin from the wood to produce a pure cellulose, as the yield will thereby be reduced. Dull coloured papers do not require a bleached pulp; on the other hand, for fine papers the cellulose should be purified and bleached to a high degree.

Rags

Actually paper was first made from cotton rags by the Chinese (see Chapter I). When, many years later, paper making spread from China to Europe, linen cloth was much more common than cotton, and linen rags were therefore used. Since these were received as worn-out, dirty clothes, the paper maker naturally followed the ordinary custom of the housewife of those days, and washed the rags by boiling them in a copper with potash. At a later date soap and washing soda, and eventually *caustic soda,* were used.

Pressure is not necessary for a boil like this, which is intended merely to clean the rags, though naturally the cleansing is quicker and more thorough if the temperature is raised by boiling under pressure. Thus steam-heated, rotating pressure boilers came to be used, though open, steam-heated pans with a vomit tube (see p. 59) up the centre remained in use in some rag mills until recently.

The modern procedure for the preparation of rag pulp has evolved in this manner, and is as follows:

Preparation of the Rags.—Although rag merchants do sort the rags they sell into grades, they seldom sort them closely enough for manufacturers of fine paper. Thus the first step in the mill is always to sort the rags. In this process buttons, hooks, eyes and any other metal pieces, and anything containing rubber (as elastic) are removed (Fig. 15). All pieces of silk, wool and artificial fibre (as *rayon*) must also be cut out if the best papers are to be made. Cotton or linen rags containing artificial fibre are sometimes used, but artificial fibres do not contribute to the strength of the paper, and are merely fibrous loading material. After sorting, the rags are cut in a rotary cutter into pieces 2–3 inches square. In some mills cutting is still done either wholly or partly by hand during the sorting process.

After cutting, the rags are dusted in a long rotating cylinder, up to about 10 feet long and 4 feet in diameter, and sloping downwards from the end at which the cut rags are added (Fig. 16). The rags are tumbled over and over as they travel slowly from the upper end of the cylinder to the lower, thus detaching all loose dust. The cylinder is a skeleton of laths and hoops and is covered with a wire gauze, through which pieces of fibre and all the dust fall, and are usually sucked away by a current of air and collected for disposal.

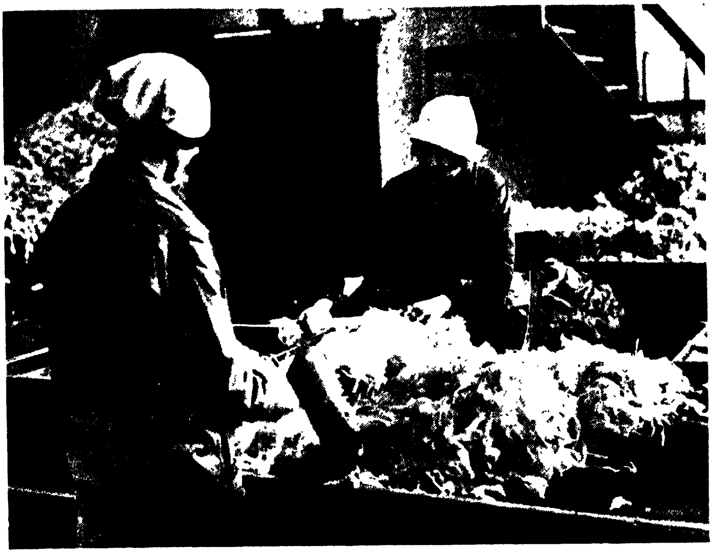

Fig. 15.—Sorting and Hand-Cutting Rags.

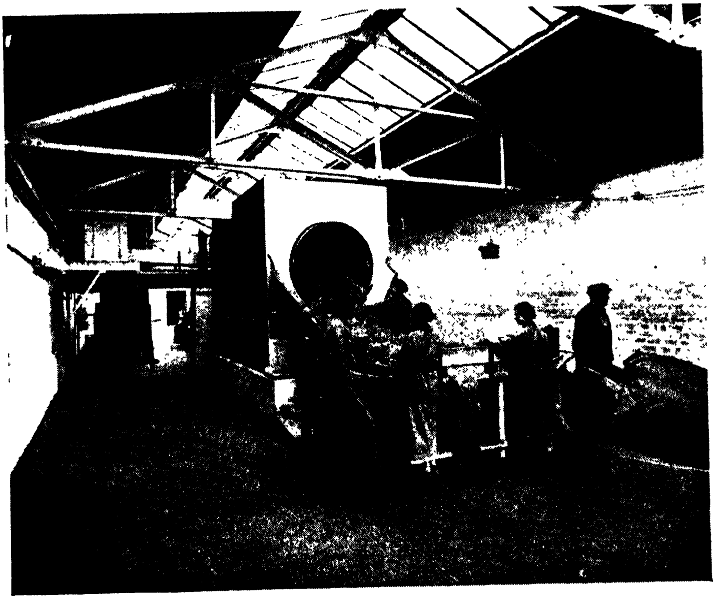

Fig. 16.—Dusting Rags.

Boiling.—After dusting, the rags are boiled in slowly rotating, spherical or cylindrical steel boilers (Fig. 17), holding from 1 to 3 tons of rags. The boiling liquor is always alkaline, containing either caustic soda, sodium carbonate, lime, or lime and sodium carbonate. Sodium silicate or clay may also be added, to help to remove grease, and recently emulsifying agents have come into use. The ratio of water to rags varies from 3–4 parts to 1, but the ratio of alkali to rags depends on the amounts of dirt, colour or sizing materials which have to be removed, and it can vary from 1 to about 15 per cent. The steam pressure used varies from 5 to 50 pounds per square inch, and the time of boiling from 2 to 14 hours. Exact details cannot be given. Rags sold under the same trade grading and required for the same paper may differ so much in the degree and nature of the dirt and dyes present, from one delivery to another, that different amounts of alkali may be needed. The skill and experience of the operative count for much here. Boiling produces no important chemical or physical change in the cotton or linen fibres of which the rags are made, but merely loosens or dissolves any non-cellulosic substances present.

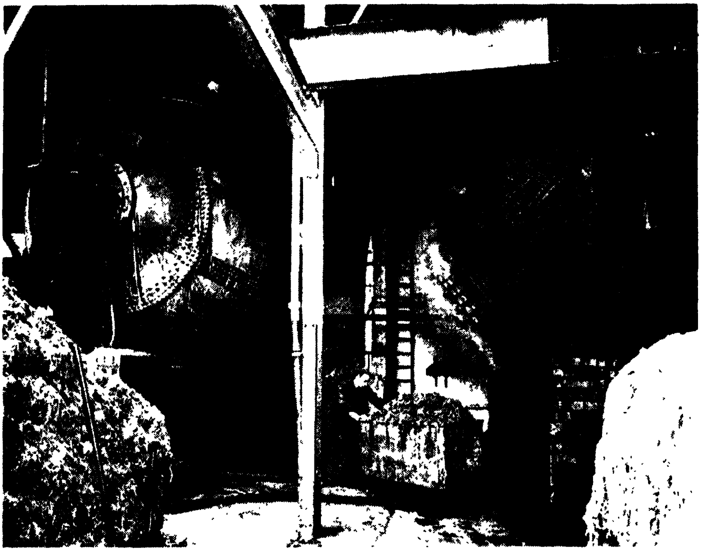

Fig. 17.—Spherical Boilers for Rags.

Breaking and Washing.—After boiling the liquor is drained off, and in some cases the alkali in it is recovered. The rags are rinsed in the boiler, preferably with hot water, from the bottom upwards, so as to float and wash away melted grease. The rags (which are still in piece form) are strained and dropped out of the boiler into boxes or draining chambers, ready for removal to the next stage, which is breaking and washing. These processes are carried out simultaneously in a ***hollander***. This consists (Figs. 18 and 19) of a wide trough, holding up to 500 pounds of pulp, with semi-circular ends (1), and partly divided longitudinally by a vertical partition (2) (the *midfeather*) round which the mixture of rags and water travels. Across the centre of the trough is a shaft (3), and on this, on one side of the midfeather, is a *roll* (4) weighing about 1¾ tons and 3½ feet in diameter and 3 feet wide. There is only a small clearance between the ends of the roll and the midfeather on one side and the side of the trough on the other, and these are kept clear of pulp by small metal strips (*bangers*).

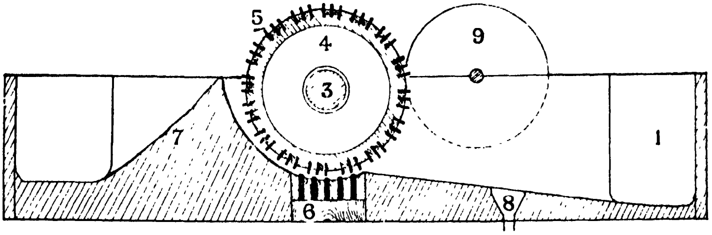

Fig. 18.—Breaker-Washer (Elevation).

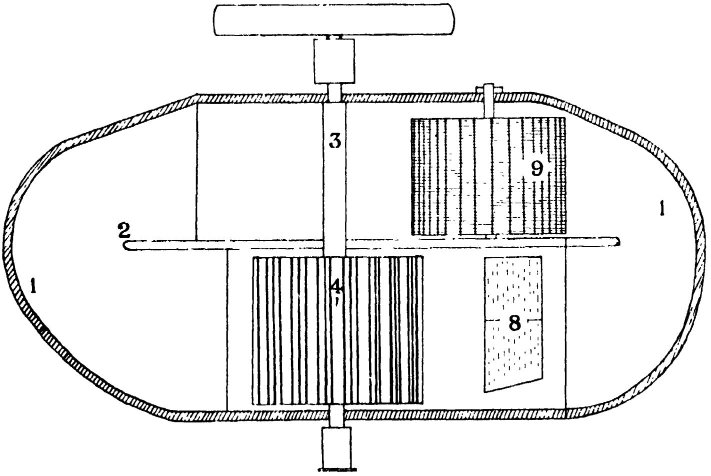

Fig. 19.—Breaker-Washer (Plan).

On the circumference of the roll are a number of slots parallel to the shaft, in which a number of steel or phosphor-bronze *bars* (5) are wedged by means of slats of wood. There are about 80 of these bars, $\frac{1}{4}$–$\frac{3}{8}$ inch thick and sometimes tapering to $\frac{1}{16}$ inch, and they project about 3 inches from the circumference of the roll. They should be blunt, so that they do not cut the rags. The roll is rotated by the shaft at such a speed that a point on its circumference moves at about 1,500 feet per minute (*peripheral speed*). This rotation and the shape of the floor of the trough serve to move the pulp around the midfeather.

Under the lowest point of the roll is the *bedplate* (6), in which about 12 metal bars are held vertically with wooden wedges. They are usually about $\frac{1}{4}$ inch thick and $\frac{1}{4}$ inch apart, and are ground so that the curved plane formed by their faces is the same as that of the circumference of the roll. The roll can be lowered or raised, so that the roll bars may be just touching the bedplate bars or be well above them.

From the bedplate, in the direction of movement of the rags, the floor of the trough rises in a curve almost following that of the roll, but widening out a little, until it reaches a point about level with the shaft. The bottom of the trough then falls, first in a rapid slope (the *backfall,* 7) and then more gently in a continuous slope right round the breaker, until the bedplate is reached again. Great care must be taken in designing the shape of the trough to avoid sharp corners and recesses, where pulp may lodge.

As so far described the rag breaker is similar to a small hollander beater, but in addition the former has a *dirt-trap* (8) and a *drum washer* (9). The former is a cavity, about 18 inches wide, in the floor of the trough just in front of the bedplate, and it is covered with a perforated or slotted plate. As the pulp travels round the trough the heavy particles of sand, buttons, metal, etc., fall to the bottom and, eventually, through the perforated plate into the cavity, from which they are periodically cleaned out. The drum washer is a device for removing dirty water during washing. It is a light, hollow drum, covered with a fine mesh wire, and driven by a shaft so that it revolves in the pulp, into which it can be lowered to a depth of 8–12 inches. The dirty water passes through the fine mesh wire to the inside of the drum, where it is picked up by scoop-shaped compartments and transferred through a sleeve surrounding the shaft to the drain. Fresh water is continuously run in to make up for the dirty water removed.

The squeezing and bruising of the rag pieces between the roll and the bedplate slowly disintegrates them into threads, and finally into the fibres from which the threads were spun, at the same time loosening any dirt held in the rag structure. During this breaking-down process, a stream of filtered water is run continuously into the trough, and removed by the drum washer. The resulting pulp of clean, freely dispersed cotton or linen fibres has then to be bleached white with hypochlorite bleaching liquor (p. 83) if it is to be used for fine papers, an operation which is also usually carried out in the rag breaker. In some mills floating dirt (such as rubber) is picked out by hand from the breaker, by girls.

The continual increase in the use of dyes which are resistant to fading and, more recently, to bleaching action is a very serious matter for the maker of rag papers. Some of the most resistant vat dyes can, however, be distributed throughout the whole mass of the rags in the boiler and also partly washed away in the liquor by boiling the rags with sodium hydrosulphite. This reduces the dye to a soluble, colourless form (*leuco-dye*) which then spreads among all the rags present, though some remains in solution and goes away when the liquor is drained off. This boil with sodium hydrosulphite is usually carried out for a short period at the end of the normal alkaline boil.

Another source of trouble is the increasing amount of artificial fibres (*rayon*) now being mixed with cotton and linen; often they are made to look so like cotton or linen that the sorters fail to recognise them. No ordinary rayons can make true paper, as they will not respond to beating (see Chapter VII). Any such fibres, therefore, which are left in the sorted rags act merely as a loading in the sheet, and so reduce its quality, especially the strength.

Esparto, Straw and Wood Waste

As the demand for paper increased, sufficient rags could not be found to meet it, and efforts were therefore made to produce paper pulp from other materials. Wood for a long time defied all these efforts, and the first material to be used successfully was straw. At that time rags were already being boiled with caustic soda in boilers heated with low-pressure steam, and it was found that if enough caustic soda was used and long enough time given, the straw could be pulped into a bleachable half-stuff, from which quite good papers could be made. Some of the papers made in this way sixty to seventy years ago still exist. Before long, however, it was found that the *esparto* plant, which grows on the shores of the Mediterranean in Spain and Morocco, was easier to pulp than straw, and yielded a pulp of unique paper-making quality. The use of esparto developed rapidly, particularly in Scotland, and the resulting papers quickly established a world-wide reputation for their printing and writing qualities (see Chapter II).

Preparation.—Esparto is harvested by pulling, not cutting, and since it grows on sandy ground it usually arrives at the mill containing a good deal of dust and sand mixed with the round, stiff, thin spikes of the plant (Fig. 20). These spikes are about 12 inches long, and on them is a dust which contains an appreciable amount of a wax, which is worth extracting for use in the manufacture of polishes if enough can be collected in one place to make the recovery worth while. The first process to which the grass is subjected, therefore, is dusting or *willowing*. This is a much more vigorous process than is rag dusting, since the stems are stiff and will stand vigorous treatment without breaking. In one method of willowing the grass is thrown in loose bundles into a rapidly revolving, open cage through which it quickly passes while being vigorously thrown round. As it does so an appreciable quantity of dust and sand is recovered, and this is the by-product from which the wax is extracted.

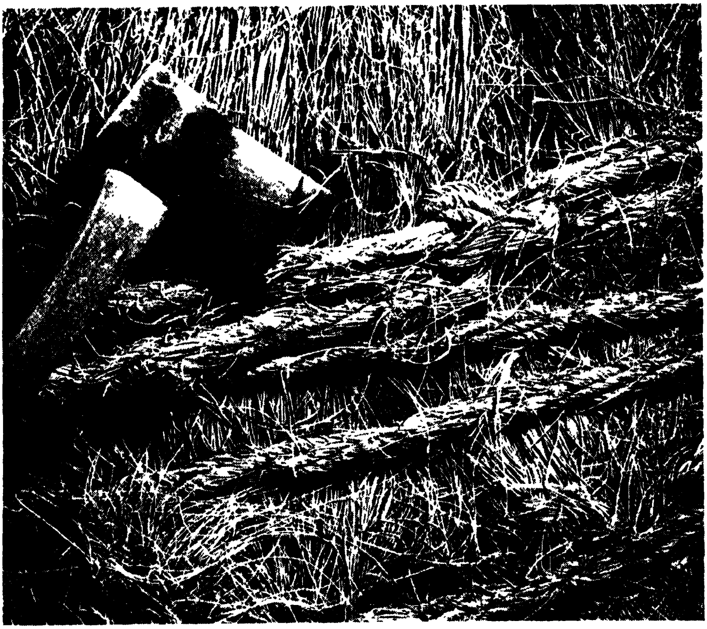

Fig. 20.—Baled Esparto Grass.

Boiling.—The small rotary boilers used for rags quickly proved unsuitable for this new pulp, and larger upright stationary boilers (*digesters*), fitted with a perforated false bottom and holding up to 5 tons of esparto, were developed. Such digesters are still in use, and are on an average about 14 feet high and 9–10 feet in diameter (Fig. 21). They are loaded through a large lid in the top of the boiler and emptied through an outlet in the bottom. To keep the

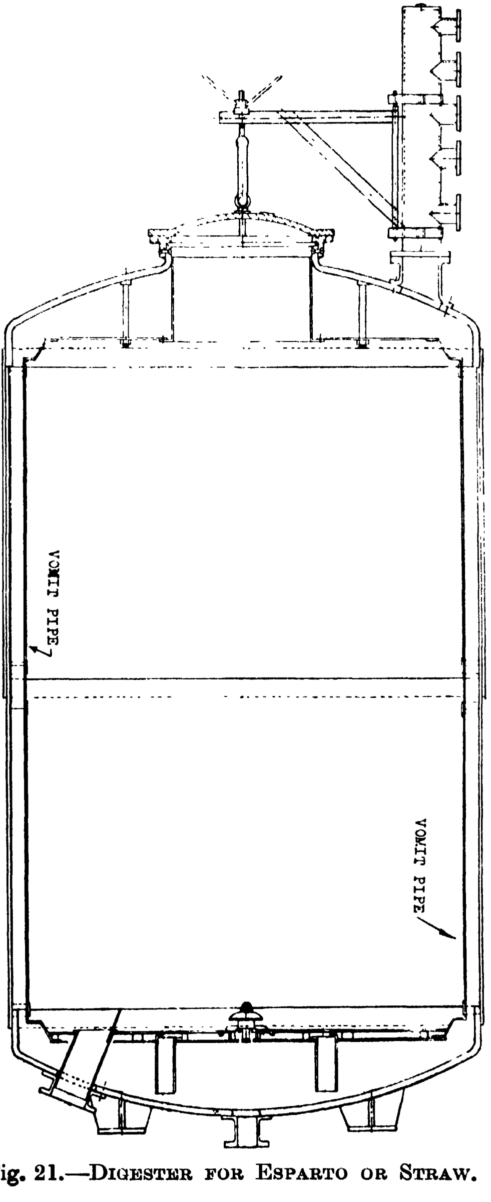

Fig. 21.—Digester for Esparto or Straw.

liquor in circulation during the digestion they are fitted (like the old-type, open rag boilers) with a *vomit pipe* up the centre, or they have several vomit pipes just inside the upright walls. The vomit pipes are set vertically in the false bottom so that when the liquor below it boils, liquor is forced intermittently up the pipes and distributed over the esparto, thus maintaining circulation. Alternatively, the digesters are fitted with an external circulation system, which draws liquor out at the base or centre and pumps it in again through a perforated ring pipe at the top of the digester. Such digesters require a liquor to fibre ratio of 4–4·5 to 1, with 12–15 per cent. of caustic soda on the weight of esparto grass for 5 hours at 45 pounds per square inch pressure of steam.

For straw more severe conditions are needed. Only 3·5–4 tons can be boiled in a digester of the above dimensions. The time required is 8 hours at 75–80 pounds pressure, and 18–25 per cent. of caustic soda on the weight of fibre must be used.

This digestion is quite a different process from the cleaning boil which rags receive. The non-cellulosic lignin which surrounds and embeds the cellulose fibres in the plant is acted upon chemically by the caustic soda, and is dissolved out into the liquor, leaving a soft mesh of free fibres suspended in the *black liquor* so formed.

Washing.—When digestion is finished the liquor is drained away to the soda recovery plant (see p. 63), since it contains sodium compounds which are too valuable to be wasted. At this stage of draining the liquor from the pulp, straw and esparto behave very differently. The latter (unless it is over-boiled) has a bulky open structure and parts with its liquor readily. Straw pulp, on the other hand, settles into a more closely packed mass, which loses its liquor much less rapidly and completely. With esparto the digesters are then filled up with water, and this wash also is drained off and sent to the soda recovery plant. The digester is then filled with water again, and this wash is allowed to run to waste. Occasionally, when the soda recovery plant is large enough, it is possible to send the second wash also to the recovery plant; or in some mills it is stored and used as the first wash in the next digestion.

Despite attempts to make straw pulp in mills designed for processing esparto, it has not yet been possible to carry out the same thorough washing of straw in the boiler because of the long time this takes. Indeed, the urgent need for output created by the war made less time available for the drainage of the first wash from the straw pulp. Thus the straw pulp always went forward to the washing and bleaching stages containing a much greater proportion of caustic soda than was ever tolerated with esparto. If straw is still to be used in peace-time (owing to the world shortage of wood pulp) then this problem of removing the liquor from the straw pulp at a concentration suitable for recovery will have to be solved. Possibly a form of rotary suction filter (see p. 89) will do this, or perhaps ways may be perfected for the digestion of straw with so much less caustic soda that recovery can be dispensed with. At present, however, while about 80 per cent. of the caustic soda used in digesting esparto is recovered regularly, 50 per cent. is an average figure with straw.

When washing in the digester is finished the pulp is usually flushed through the bottom outlet by a high-pressure jet of water directed on to the pulp through the lid-hole. In the case of esparto the whole plant, except for a few hard parts of root, which really should not be pulled up when the plants are gathered, disintegrates completely into free fibres. The root portions are most undesirable, and every effort is made to avoid breaking them up before they can be screened out. Where arrangements have been made for such screening to take place before bleaching (*green straining*) this is easily ensured, but where, as in some mills, straining does not take place until after bleaching, the bleaching is best done in potchers provided with pump circulation and therefore having no rolls which might break up the roots.

Straw, on the other hand, is never completely defibred in the digester, and the incompletely pulped portions (which may be thistle, dock and nettle stems and a few harder straw stems) have too much paper-making value to be wasted. They are therefore sometimes screened out before bleaching and sold to board mills; or added to subsequent boilings; or, better still, the pulp from the digester is well broken up in potchers fitted with barred rolls and bedplates. The stems are then in a condition in which the bleach liquor used can attack them and complete the disintegration. Most of the remaining caustic soda and other soluble matter is washed out in the potchers, or breakers, before the bleach is added, by means of the usual drum washers, as described for rags (p. 55).

Bleaching (see also Chapter VI).—After washing, the warm pulp is bleached with 10–15 per cent. of bleaching powder on the weight of esparto pulp present. Bleaching takes longer in the case of straw than it does with esparto, and it is customary to use more bleaching agent (15–22 per cent.). Without additional equipment therefore, the same output of bleached pulp cannot be obtained. This is provided by the increased use of bleaching towers in which the mixture of pulp from the potchers and bleaching agent is held to complete the bleaching. In most modern mills the bleaching agent is the solution made by passing chlorine gas into lime and water, but the bleaching action is the same as that produced by bleaching-powder solution (see Chapter VI).

The bleached pulp can be washed in potchers fitted with washing drums or, when towers are used, the pulp is preferably greatly diluted and then concentrated again and washed on a rotary vacuum filter (p. 89) or *press(e)-pate* (a short machine wire with couch rolls, see p. 91 and Chapter IX). Before concentration the diluted pulp should be passed over sand tables and screened (see p. 82) to remove sand, grit, shives (see p. 61) and undispersed clumps of fibres.

Since esparto parts with its liquor in the digester more readily than straw pulp, so on the press-pate or rotary filter the same applies, and esparto can be taken off as a much thicker layer than straw. From this point of view, therefore, esparto is preferable to straw. Other operating advantages are its higher pulp yield (40–44 per cent. as compared with 30–33 per cent. for straw); its lower chemical consumption; and the higher soda recovery it allows (see below).

Wood Waste (from wood-working factories or even lumbering operations) is another material which can be easily pulped in an ordinary esparto digester. It is, however, necessary to be very careful in the selection of the wood from which the waste comes, and to refuse mixed waste. The soft or coniferous woods cannot be pulped at less than 100 pounds per square inch steam pressure, but a number of hardwoods pulp quite easily even at 45 pounds. Birch, oak, elm and willow digest very easily; beech and sycamore are distinctly more resistant.

The state of division of the wood is important. The caustic soda penetrates the wood in the grain direction, and if the thickness of the wood in this direction is less than ½ inch, complete disintegration will take place in 6–8 hours. The dimensions in the other direction are much less important, and ½-inch slices taken across the whole trunk of a tree digest easily. Bark disperses almost completely during digestion, and any residue bleaches readily. Knots are harder to digest than the wood, but where green straining is possible they can be screened out. Otherwise it is necessary to pulp the knots, and as more caustic soda is required, a weaker pulp results; 28 per cent. of caustic soda and an 8-hour boil at 75 pounds per square inch pressure will pulp birch, oak, elm, or willow, but if the knots must also be dispersed 35 per cent. of caustic soda will be needed.

It is a great advantage to mix some digested wood waste with the straw pulp before the press-pate is reached, as the mixture parts with its water on the press-pate much more readily than does straw pulp alone. The mixture, too, wets less in the beater (see Chapter VII) and makes a closer, less rattly and bulkier final sheet of paper.

The processes used for the preparation of bleached pulp from esparto, straw or wood waste are identical in principle with those used for the manufacture of wood pulp by the soda process; the differences are those of detail and technique. This chapter should, therefore, be read in conjunction with Chapters V and VI.

Soda Recovery

Pulping processes involving the consumption of considerable quantities of caustic soda necessitate the recovery of the alkali for economic reasons. Also, the alkali dissolves large quantities of organic matter, the direct discharge of which into streams would give rise to complaints from the river authorities. Hence the need for treating the digester liquors from the alkaline pulping of esparto, straw and wood. The problem is that of destroying the organic matter and converting economically the dissolved organic sodium compounds into sodium hydroxide.

Varied attempts to do this have been made. Thus the organic matter can be precipitated by acid or lime, but only incompletely, and the process is uneconomical. The only process which is practicable to-day is to concentrate the liquor and to incinerate the product in order to convert the organic sodium compounds to sodium carbonate, which can then readily be causticised to the hydroxide.

Evaporation.—To minimise the expense of concentration, dilution of the spent liquor must be avoided so far as possible; therefore the washing of the pulp should be as economical in the use of water as is compatible with complete removal of the soluble matter. The digester liquor and those wash waters containing sufficient caustic soda to justify treatment are filtered to remove fibre, and fed from storage tanks to the evaporators. These are usually of the *multiple effect* type, usually triple or quadruple. Each effect usually consists of a vertical cylindrical vessel divided horizontally into three compartments. The top and the bottom are connected by a number of tubes passing through the central chamber, the steam chest. The liquor is admitted to the bottom and top sections, and hot steam enters the central steam chest so as to surround the tubes containing the liquor. The result is that the liquor boils and water is evaporated, the steam being drawn away from the top of the effect. The steam used for heating is thereby condensed, and the resulting water drains away from the bottom of the steam chest.

The vapour evolved from the liquor contains practically all the heat put into the plant, as latent heat, and is capable of evaporating more liquor if led into the steam chest of a second effect—provided always that the heat can be transferred to the liquor in the tubes of that effect. For such transfer of heat to occur it is essential that there should be a difference of temperature. Use is therefore made of the fact that a liquid boils at a lower temperature when the pressure over it is reduced. The vapour outlet of the second effect is therefore connected to a vacuum pump or other device, which lowers the pressure in the effect. In this way a given amount of heat can be made to evaporate two separate batches of water.

The latent heat still contained in the vapour from the second effect can be made to evaporate a third quantity of liquor, provided that the pressure can be again reduced far enough. The principle can be carried still further, but there is a limit to the number of effects which can thus be connected in series because the pressure cannot be reduced to a complete vacuum; also, with the introduction of each additional effect the average temperature difference attainable in any one effect is reduced. The number of effects is, therefore, usually three or four.

A triple-effect evaporator (Fig. 22) will thus consist of three effects, the liquor being fed into the first. The steam supply is usually pass-out steam at low pressure, say 5–15 pounds per square inch. The partly concentrated liquor from the first effect is fed into the second effect, and after further concentration to the third effect; the gradual drop in pressure throughout the series enables this flow to be controlled easily by a cock. The vapour from the first effect passes into the steam chest of the second, and that from the second to the steam chest of the third effect. The vapour from the last effect is taken to a jet condenser (usually of the barometric type), and a pump removes any air which leaks into the plant. The concentrated liquor from the last effect must be removed by pumping while hot.

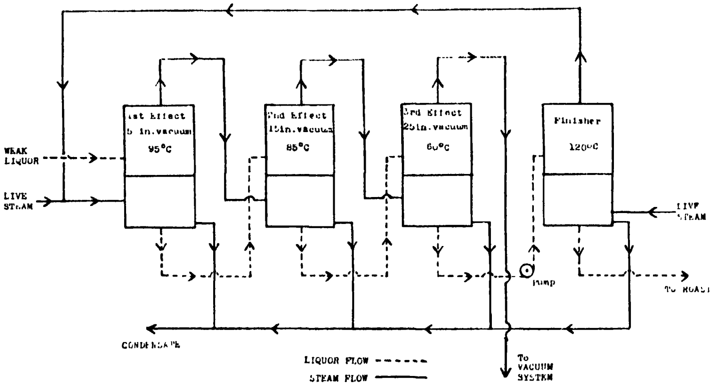

Fig. 22.—Flow Diagram of Triple-Effect Evaporator.

In order that the thick liquor will burn readily, its moisture content should be as low as possible, provided that it will still flow through the pipes. Unfortunately, as the temperature is reduced the liquor becomes more treacly and it may tend to congeal. For this reason it is usual to add an extra effect (the *finishing pan*) at the beginning of the series, where the steam is first used and the temperature consequently is higher. This practically converts the plant into a quadruple-effect evaporator, with the fresh liquor entering the system at the second effect.

Incineration is carried out in a rotating cylindrical oven or roaster (Fig. 23), 10–14 feet in diameter, and up to 30 feet long, revolving about once per minute. It is first heated up by a coal-fired grate, the hot gases from which pass through the roaster and, after passage through a dust-collecting chamber, to a waste-heat boiler and a chimney. The hot, concentrated liquor from the evaporators is fed in at the chimney end, and if the moisture content is low enough it soon begins to burn to a coky mass, which works its way to the other end and issues as granular *black ash* consisting of a mixture of carbon and sodium carbonate. Once the roaster has become thoroughly hot, however, the combustion of the organic matter in the liquor should produce sufficient heat to keep the roaster going without the use of other fuel, and the steam from the waste heat boiler should supply most of that required in the evaporator.

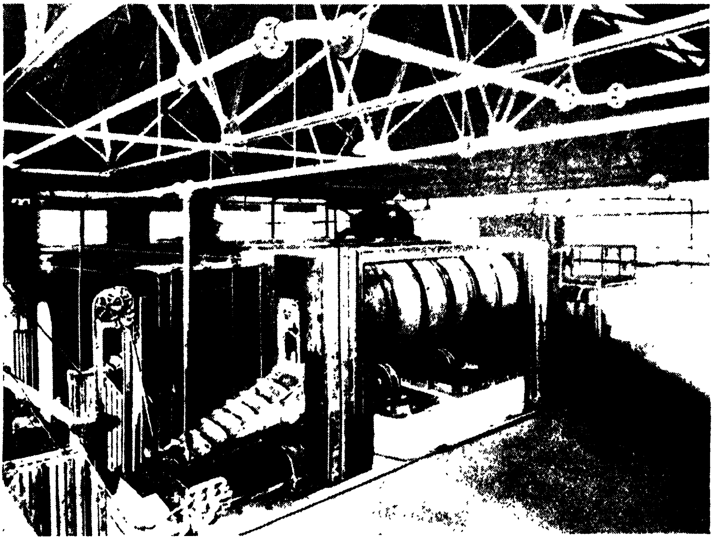

Fig. 23.—Soda Recovery: Roaster.

Lixiviation (leaching).—Formerly the black ash was leached in tanks with hot water, to dissolve out the sodium carbonate, leaving the insoluble carbon as a residue. Not only was the disposal of the carbon a nuisance, but there was always a slight loss owing to the difficulty of removing the last traces of alkali from it. Steps are

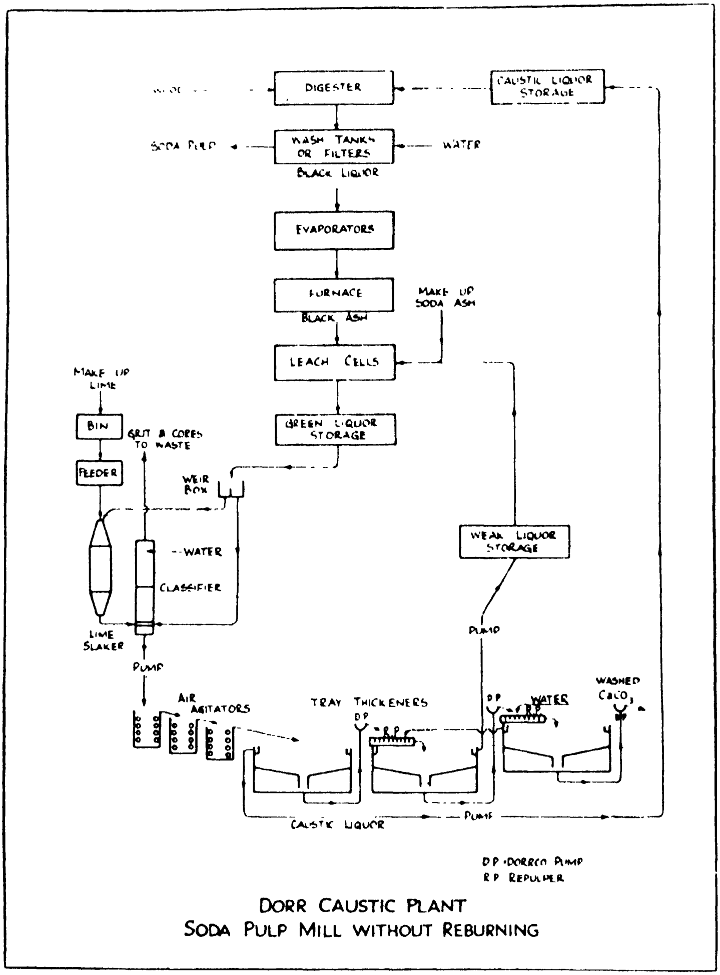

Fig. 24.—Soda Recovery: Flow Diagram for Continuous Causticising.

therefore taken, in some mills to burn off most of the carbon. One way of doing this is to allow the black ash to discharge from the roaster on to a slowly travelling chain grate about 6 feet long, when air passing through the mass burns off a large proportion of the carbon. On addition to water this yields a solution of sodium carbonate. In other cases the black ash passes to a smelter, where the residual carbon is burnt away more rapidly by means of a blast of hot air.

Even in a well-regulated plant it is not possible to recover all the caustic soda added to the digester, as losses occur at several stages in the process. Thus some of the washings from the pulp are too dilute to justify the cost of evaporation; some alkali is lost in the evaporator; dust carried away in the flue-gas from the roaster contains alkali; and there is also a slight loss on causticising. Rarely does the proportion of caustic soda recovered exceed 80 per cent. with esparto, and with straw it is usually about 50 per cent. The loss is made up just before causticising by the addition of *soda ash* (sodium carbonate).

Causticising is still usually carried out as a batch operation, though in the larger plants it is preferable to make it continuous (Fig. 24). The solution of sodium carbonate is treated with calcium hydroxide in the form of milk of lime, when it is converted to sodium hydroxide with the simultaneous precipitation of the lime as calcium carbonate. Unfortunately the reaction does not go to completion even under the most favourable conditions. Boiling and agitation assist, but the causticisation seldom exceeds 92 per cent. The sodium left unchanged as carbonate in the caustic soda liquor has no ill effect, but is too mild an alkali to be of maximum benefit during digestion.

The plant used for batch causticising frequently consists only of a tank with a steam inlet and, possibly, an agitator; it is so arranged that, after settling out the calcium carbonate, the clear caustic soda solution can be run, perhaps through sand or a wood-wool filter (to retain particles of carbon), to the stock tank used for filling the digester. The settled *lime sludge* from the causticiser retains some caustic soda, and therefore requires washing, preferably on a rotary filter. It is then usually discarded, although it can be used as a dressing for agricultural land requiring lime. Reburning to convert it to the oxide, or purification to produce a loading for paper, is justified only in certain cases.

CHAPTER V

PULPING METHODS—WOOD

THE "Historical Account of the Invention of Paper," by Matthias Koops, published in 1800, was printed partly on paper said to be made from wood. No particulars are given of the treatment it received, but the result was a buff-coloured sheet containing much undisintegrated material. It was not, however, until the introduction of mechanical wood pulp by Keller in 1844 and of a chemical process for the pulping of wood in 1854 that the wood-pulping industries really started; in 1938 these produced 8½ and 13½ million tons of pulp, respectively.

At the present time there are many different brands of wood pulp. They range in quality from low-grade, brown or white, short-fibred, mechanical pulps, which serve in paper as little more than a filling material, to cellulose pulps which are sufficiently pure for the manufacture of rayon and explosives. Their importance will be realised from the fact that wood pulps comprise about 80 per cent. of all the fibrous raw materials used for paper making throughout the world.

Varieties of Pulp Woods.—Almost every variety of wood can be pulped, but economic and other reasons restrict those used to a few only. These can be divided into two broad classes, viz. those from *coniferous* or cone-bearing trees (such as spruce), and those from the *deciduous* trees, which shed their leaves annually. These classes are frequently spoken of as the soft and hard woods respectively. This classification may, however, be misleading, and a paper maker tends to think of them rather as the long-fibred and the short-fibred woods, respectively.

Coniferous trees are the source of the majority of wood pulps, both mechanical and chemical, and of them the varieties most used are the spruces and the pines. In the eastern hemisphere Norway spruce (*Picea excelsa,* Fig. 25) is the usual raw material for white mechanical pulp and for chemical pulp produced by the bisulphite process (*sulphite pulp*). The reasons for this preference for spruce are its good white colour, length of fibre, comparative softness, and relatively low resin content. Pine (Fig. 26), which in Europe is usually Scotch pine (*Pinus Sylvestris*), though frequently called Scotch fir, has a lower colour and is not, therefore, so suitable when a white mechanical pulp is required. It also contains a larger proportion of resin, and the chemical treatment is therefore usually digestion with an alkali, such as a solution of caustic soda (*soda process*), or of a mixture of caustic soda and sodium sulphide (*sulphate* and *kraft* processes). These particular varieties of spruce and pine are not indigenous in the western hemisphere, but similar native spruces and pines serve equally well. A smaller proportion of pulp is made from deciduous trees, mainly from the poplars, and in particular aspen (*Populus tremuloides*). Other soft and hard woods used occasionally are hemlock, fir, eucalyptus (mainly in Australia), larch, beech and birch.

Fig. 25.—Spruce Trees.

Fig. 26.—Pine Trees.

The supplies of spruce (known as white deal when imported as lumber), and pine (called red or yellow deal when sawn), come mainly from northern Europe and North America. It is to be expected, therefore, that countries with a temperate to sub-arctic climate are the best sources of pulp wood, and it is in such countries that the wood-pulp mills are usually situated. They tend naturally to be near to the forests and in the case of mechanical pulp mills, in which the power consumption is high, in the neighbourhood of cheap water power; similarly, chemical pulp mills must be near a copious supply of water for washing. In Great Britain the inadequacy of home-grown timber supplies necessitates the use of imported pulp wood, and therefore it is not surprising that few wood-pulp mills exist here.

The suitability of timber for pulping depends on several factors. Thus, the rate of growth of a tree depends on the soil and on the climate; in the northern hemisphere it will probably be greater on the southern than on the northern face of a hillside. The effect of this difference can be seen in the widths of the annual rings and in the specific gravity of the wood. A quickly grown tree may have only three or four rings to the inch, whilst a slowly grown tree has forty or more. Consequently, the wood of the latter is the more compact, harder and has a higher specific gravity. Whether the pulp from a slowly grown tree is stronger than that from soft, light timber is doubtful; in any case, the difference is slight. The specific gravity of the timber may, however, be a matter of considerable importance to the pulp maker from the economic aspect, because the logs are usually bought by volume and the pulp sold by weight. Hence heavy timber is the more profitable.

Forest-grown timber is superior to that grown in more open surroundings. Owing to the proximity of other trees and the demand of the tree for sunlight, a forest-grown tree tends to produce a long, straight log comparatively free from knots, the lower branches having died through lack of light. A straight, circular log is more easily cleaned from bark without waste of timber than is a crooked or furrowed log. Knots from coniferous trees are hard, short-fibred and resinous, and if not removed tend to yield dirty specks (*shive*) which detract from the appearance of a pulp or paper containing them; knotty wood is therefore avoided when possible.

Structure and Composition of Wood.—In order to understand the pulping process it is desirable to have some knowledge of the physical structure of a tree and of the substances of which it consists. A microscopical examination of thin sections of wood (see Fig. 27) shows that a log is made up of fibres running parallel with its length. That the fibres vary in diameter and in the thickness of the cell wall is seen when the wood formed in the spring is compared with the summer wood. It is this difference which causes the annual rings visible at the ends of a cut log. Occasionally gaps occur between the fibres; these may contain resin or, in the case of the deciduous trees, thin-walled vessels characteristic of the variety of tree.

Chemically, wood consists of three main constituents or groups of compounds. Rather less than half is cellulose (see Chapter III), an organic compound allied to the starches and the sugars. It has, however, a valuable characteristic in that it is relatively resistant to chemical attack, a property which renders possible various chemical methods of isolating it from associated material. Next in amount is the group of compounds known collectively as *lignin.* The combination of cellulose and lignin is known as *lignocellulose.* Lignin differs materially from cellulose in that it contains what the chemist calls unsaturated groups of elements, and on this account it is readily attacked by certain chemicals such as chlorine.

The bulk of the remainder of the wood substance is called *hemicellulose.* This, however, is not a single compound but consists of several allied compounds of imperfectly known structure and having different degrees of resistance to chemical attack. Some of these compounds are almost as resistant as is cellulose itself; while others, such as the wood gums, decompose comparatively readily, the products being sugars and similar compounds. A consequence of this variation in resistance to attack is that a pulp produced by a chemical process contains more or less hemicellulose according to the

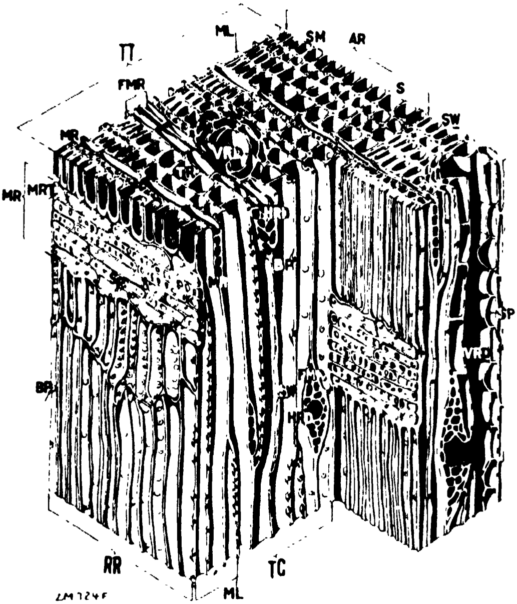

Fig. 27.—Diagram Showing the Fibrous Structure of Coniferous Wood.

TT, TR. Fibres. S. Spring-wood fibres.
SM. Summer-wood fibres. AR. Annual ring.
MR. Medullary rays (food storage). VRD, HRD. Resin ducts. SP, BP. Pits in fibres (to convey sap).

severity of the treatment. Both the purity of the pulp and its yield are thereby affected. Thus high yields are obtained at the expense of the purity of the cellulose. If a pulp is to be used for paper making it is seldom essential to have very pure cellulose; in fact, for some purposes (such as greaseproof papers) this may be a disadvantage. However, when the wood pulp is a starting-point for the production of rayon or explosives, the purity is usually so important that the yield and cost of production are minor considerations.

Apart from the resin content the minor constituents of wood rarely have any great influence on the pulping process or on the product. An exception is wood containing tannins (such as eucalyptus) which may develop an objectionable colour in contact with iron. However, the proportion of resin, though it may be small, may be important in determining whether a wood can be pulped by the bisulphite process. Spruce which contains about 1 per cent. can be so treated; but Scotch pine, with 2 per cent. or more, is so resistant to penetration by the acid bisulphite liquor that this process is not practicable.

Collection and Preparation of the Wood.—The trees are usually felled during the autumn, as the wood then contains less sap and therefore is less liable to decay on storage; use may also be made of frozen ground to skid the logs to convenient streams or loading points. Branches are removed and the logs are cross-cut into lengths suitable to the mode of transport. If use can be made of a river to float the logs to the mill there is no necessity to remove the bark in the forest, as much of it will be rubbed off during its passage down the stream. On the other hand, where logs have to be loaded on sledges or railway wagons they are peeled in order to reduce their volume.

On arrival at the mill long logs are cross-cut into lengths more convenient to handle or, if for mechanical pulp, most suitable for the grinder. They may then be used at once or stored. Provided that decay (with consequent loss and discoloration of the wood) can be avoided, the use of stored wood has advantages despite the cost of extra handling, because it will be more uniform in moisture content; the regular working of the mill will not be interrupted by weather or other conditions affecting the supply; and, with the bisulphite process, less trouble is likely from resinous substances (*pitch*) in the pulp.

Before use the logs must be cleaned from any bark still adhering (*barking*) and from any dirt picked up on the journey from the forest. Bark contains no fibre, and it either produces dirty specks or consumes chemicals for its removal from the pulp. At one time barking was carried out by hand with *drawknives* and chisels, but the increasing cost of labour led to the introduction of mechanical methods. One of the earliest was the disc barker, on which the log was slowly turned while held (usually by hand) on a ledge against a revolving disc, through which projected slightly three or four knives arranged radially. These shaved off the surface of the log effectively, but in doing so were liable to remove an excessive amount of good wood, especially from a log which was not straight and round. As such loss is serious the disc barker has largely been replaced by machines in which the bark is rubbed rather than shaved off, such as the tumbler drum barker (Fig. 28). This consists of a large, horizontal skeleton cylinder made of steel sections, through which the logs are passed either under water sprays or actually immersed in water. The bark is softened and rubbed off by the tumbling action without damage to the wood underneath, though even in this case crooked timber causes difficulties. Logs which are unduly large in diameter are split. Formerly the knots were drilled out, but this is unusual nowadays. Since the next stage of the process depends on the class of pulp to be made, the different pulping processes will now be dealt with separately.

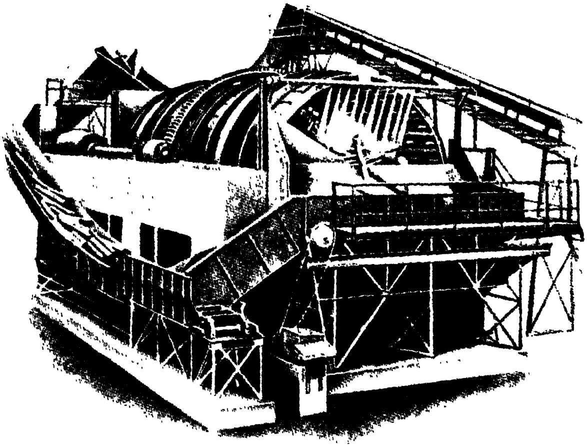

Fig. 28.—Drum Barker for Wood.

Mechanical Wood Pulp (or **Groundwood**) as the names imply, is produced by a mechanical grinding process. Logs are pressed against a revolving grindstone, while a stream of water playing on the stone washes away the pulp as it is scratched off the wood and simultaneously prevents the stone from becoming unduly hot. The pulp so produced consists of broken fragments of fibre together with bundles of fibres which have been torn away from the wood (*shive*).

The particles of disintegrated wood still retain the lignin and other compounds which cemented the fibres together in the log, and they are therefore stiff and unable to felt together to form a strong sheet of paper. The lignin is more reactive than the cellulose, so that paper made from the pulp deteriorates on exposure and is not permanent. This is readily demonstrated by the effect of a few hours of summer sunshine on a sheet of newsprint, which usually contains from 75 to 80 per cent. of mechanical pulp. The paper turns yellow or brown and becomes brittle. Fortunately the presence of mechanical wood in a paper can be detected readily by the red colour obtained when the undyed sheet is spotted with *phloroglucinol solution.* On the other hand, the yield of mechanical pulp is high (about 95 per cent. on the weight of the barked wood), so that such pulps are relatively cheap despite the high power-consumption involved; their use for ephemeral matter is therefore fully justified.

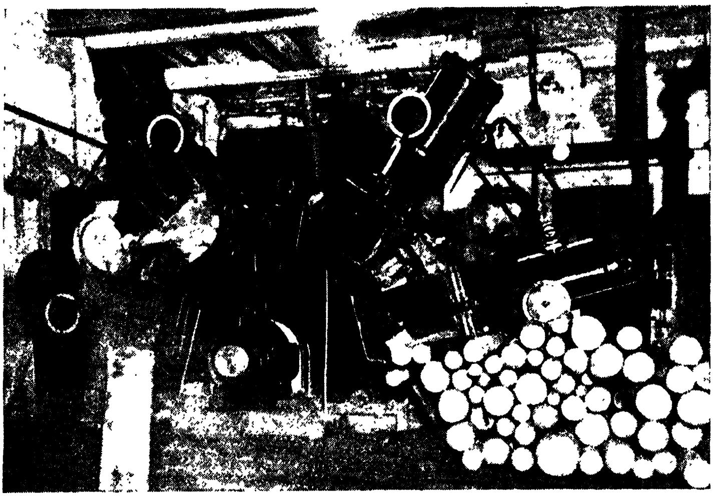

Fig. 29.—Grinder for Wood.

In the grinder (Fig. 29) the stone is usually mounted on a horizontal shaft and driven by an electric motor. Formerly all stones were of natural gritstone, similar to that quarried in Derbyshire, but nowadays artificial stones tend to displace them. They are the more expensive, but are more uniform in texture and the size and sharpness of the grit particles are more easily controlled. Even when the best type of stone has been selected it is still necessary to "sharpen" the grinding surface from time to time by pressing against it a revolving steel roller (a *burr*) covered with flutes or diamond-shaped points. The points on the burr dig into the surface of the stone where it is becoming smooth. The wood is always pressed against the stone with the axis of the log parallel with the shaft of the stone, the length of the log being approximately the same as the width of the stone. The devices for holding the logs vary; in the older *pocket-grinders* two to five rectangular bottomless boxes (pockets) are arranged round the periphery of the stone, and hydraulic rams force the logs in the pocket against the stone, returning automatically when the wood has been ground away and the pocket requires refilling. In a later type, the *magazine grinder*, there are only two pockets, which fill automatically on the return of the ram, thereby reducing labour and lost time. There are also *continuous grinders*, in which the logs are jammed in a feeding device such as two pairs of endless caterpillar tracks moving down the sides of a single pocket.

The pulp formed falls into a pit below the stone. At this stage it contains *slivers* (thin pieces of the logs which have passed under the sides of the pocket) and large shives, which would detract from its value. They are removed by passing the diluted pulp through two screens (see p. 81) in series. The first (*bull-sliver screen*) has round holes about 20 millimetres in diameter; and the second (usually a centrifugal screen) has openings about 1 millimetre in diameter. Rejected material from the first is frequently discarded, though it may be treated in a hammer mill or similar disintegrator and made into boards. The shives which will not pass the fine screen go to a refiner, which may consist of two stone discs like those of an old-fashined flour mill, between which they are reground before being returned for re-screening.

Finally, the suspension of purified pulp flows over sand-traps (see Chapters VI and VIII) before being concentrated. If the pulp is to be used in the same mill as that in which it is prepared, it is taken to concentrators (see p. 85), which concentrate it to about 5 per cent. consistency. If it is to be sent away, it is made into laps on a kind of board machine; or run over a presse-pate (see p. 91) to convert it to sheet form. The laps will probably be pressed and baled to be sold as "moist," containing about 45 per cent. of dry pulp. The web may be passed over drying cylinders and sold as air-dry pulp.

The quality of the pulp from a particular wood is influenced by the volume of water used on the grinder. With a restricted supply the temperature rises owing to the friction between the stone and the wood. The temperature attained momentarily at the plane of contact is difficult to assess, because the heat is quickly dissipated; nevertheless it is sufficient to lower the colour of the pulp, presumably as a result of scorching. Another effect of heat is to soften the wood, so that longer pieces of fibre are rubbed off. At the same time there is a tendency to tear off larger bundles of fibre, so that the pulp is more shivey. On the other hand, when plenty of water is used on the stone the temperature is kept down, with the production of a better-coloured, shorter-fibred pulp, with fewer shives. While hot-ground pulp is usually preferred for newsprint, the cold-ground pulp is used in better-grade papers, in which it serves as a fibrous filling material, contributing to the opacity of the sheet.

Until recently it has not been possible to bleach mechanical wood pulp effectively. A solution of calcium bisulphite certainly brightens the colour, but with loss of the sulphur dioxide the colour tends to deteriorate. In recent years, however, sodium peroxide has been used much more successfully.

A comparatively small proportion of brown mechanical wood pulp is produced by grinding logs which have been softened by steaming or by boiling in water alone. This pre-treatment dissolves about 10 per cent. of the wood substance, and the yield is correspondingly less. The resulting fibre particles are longer, and many fibres are removed whole during grinding, but the proportion of shives present may be much higher. Unfortunately the treatment turns the wood a brown colour which, up to the present, it has not been possible to bleach effectively. Such *semi-chemical* pulp is used in the manufacture of cheap wrappings, thin machine-glazed pattern papers, leather boards, etc.

The Chemical Processes

The chemical treatment of wood involves penetration of the wood by a solution. For this to be effective in a reasonable time the wood must be in small chips, and as penetration takes place mainly along the grain of the timber, it is the length of the chip which is important. The barked logs are sliced obliquely on a (usually rotary) chipper (Fig. 30), the thickness of the slice along the grain being ¾ to 1 inch. The slices break up readily, but are passed through a hammer mill or other disintegrator to complete this action. The disintegrated material is taken to a chip screen with two sections having different meshes. This divides it into three grades, namely, the dust, the good-sized chips (about ¼ inch thick and ¾ inch wide), and the over-size chips and knots. The dust is discarded, as it contains dirt.

The over-size material may be returned to the disintegrator to obtain more good chips, but in view of the knots present (which break up and produce resinous specks) it is safer to use it for a second quality (*knotter pulp*), especially with the bisulphite process. Uniformity of chip size is advantageous, as the wood is thereby cooked more uniformly. Chip bins with sliding bottom doors are placed over the digesters to facilitate filling. As stated earlier, there are two main classes of chemical wood pulp, but the wood for both receives the same treatment up to this stage.

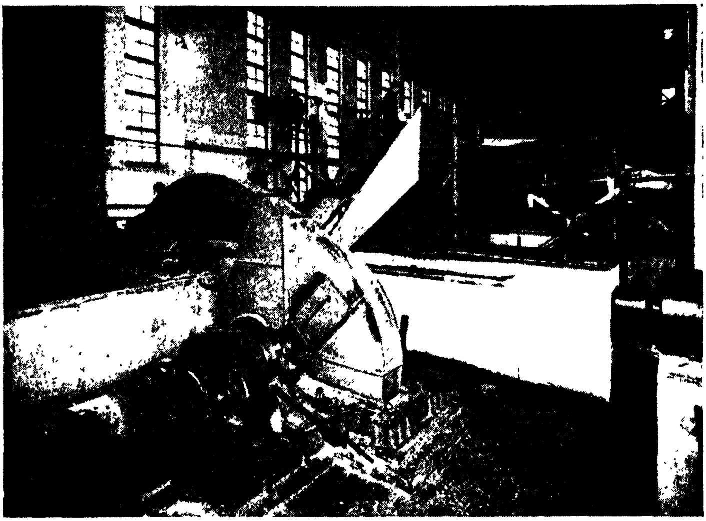

Fig. 30.—Chipper for Wood. Barker in Background.

The Bisulphite Process.—The digesting liquor contains sulphur dioxide with bisulphite of calcium or a mixture of the bisulphites of calcium and magnesium. It is always prepared in the pulp mill, the starting point being either sulphur or iron pyrites. When burned or roasted these yield sulphur dioxide, which is allowed to act on limestone in presence of water, or on milk of lime; the resulting solution is strengthened with the gases evolved from previous digestions, and then serves as the cooking agent. A common type of plant for making the liquor consists of two towers filled with lumps of limestone, over which the liquid trickles, while the cooled burner gas is blown in at the bottom. The towers are worked in series on the counter-current principle, the liquor being circulated through both while the gas is also passed through both, but in the opposite direction. The liquor in the digester contains 4–7 per cent. of sulphur dioxide, of which about 1·2 per cent. is combined with the calcium or magnesium.

Since the liquor is acidic and will attack the shell of a mild-steel digester, this vessel must be lined with acid-resisting material (usually tiles set in acid-resisting cement) or made of an acid-resisting alloy. The digesters may either rotate or (more frequently) be stationary and vertical (cf. Fig. 21 p. 59). Fittings such as test cocks and valves must be of acid-resisting metal (bronze or stainless steel). Heating is by steam (usually direct) at about 100 pounds per square inch pressure. The cooking is carried out according to a temperature schedule based on the experience of the operator; the duration varies from 6 to 24 hours or longer, according to the class of pulp desired. A short cook yields a strong pulp, which normally cannot be bleached economically; whilst a longer cook produces softer pulps suitable for subsequent bleaching (Chapter VI).

The sulphur dioxide in the liquor exerts an appreciable pressure, and unless a very high steam pressure is used, it would not be possible to raise the temperature sufficiently to obtain satisfactory digestion; the actual maximum temperature attained is 130°–150° C. It is for this reason that, after the pressure in the digester has been raised to that of the steam supply, the gas is relieved from the digester, either continuously or intermittently with a stationary or rotary digester, respectively. The gas evolved is cooled by passage through condensers, and used to enrich the raw liquor (see above). The control of the temperature by means of this relieving process requires considerable experience in order to produce regularly a pulp of a desired character. The more drastic the cooking treatment the greater is the decomposition of the lignin and especially of the hemicellulose. At the end of the cook the steam and gas are released, the digester emptied, and the spent liquor washed out. Subsequent treatment of the pulp is on similar lines to that described above for mechanical pulp; thus, it is passed through appropriate screens, over sand traps, and concentrated.

The bisulphite process is used to produce some of the purest forms of wood cellulose, such as the so-called *alpha pulps*, which, however, receive an additional alkaline treatment. The papermaking grades find extensive use in many classes of paper, such as wood-free printings and writings; they tend to make the sheet hard, compact and possibly somewhat translucent. They also provide long fibres for admixture with short-fibred pulps like esparto and straw; and they blend well with rag pulps.

The yield is 45–55 per cent., so that about half the weight of the wood is removed in solution in the spent digesting liquor. This spent liquor is used in the tanning of leather, for briquetting, for cores in foundry work, and for numerous other purposes, but these outlets absorb only a small proportion of the amount available. During digestion the hemicellulose is decomposed with the formation of sugars, which can be fermented to produce alcohol or yeast, but unless the object of pulping is to produce a pure cellulose which is free from hemicellulose, it is not rational to sacrifice pulp in order to obtain a high yield of alcohol. Yeast can serve as a food for man or animals and such use has been made of it in Germany; whether this will be more than a war-time measure is as yet uncertain, but it seems that liquors from beech are more suitable than those from spruce wood. In any case the sugars comprise only a small proportion of the organic matter present in the spent liquor, so that their conversion into alcohol does not prevent loss of the bulk of the non-cellulose part of the wood, nor does it prevent pollution of the streams into which the liquor is discharged. It is doubtful whether attempts to utilise the organic matter as a fuel are economical, as the removal of the water from the spent liquor by evaporation requires heat.

The Alkaline Processes (see also Chapter IV).—The original method for the pulping of wood, evolved by Watt and Burgess (1854), depended on the action of caustic soda. The comparatively high costs of sodium compounds and the large amount required for digestion (at least 25 per cent. on the weight of wood) render it economically desirable that they should be recovered from the spent liquor for re-use. Even in a well-organised plant it is hardly possible to recover more than about 90 per cent. of the soda, and so the loss is made up by the addition of soda ash, which together with the recovered soda is causticised with lime (see Chapter IV). Efforts to find a cheaper source of sodium compounds than soda ash led Dahl, in 1884, to try sodium sulphate (*salt cake*). The sulphate takes no active part in the digestion, which is carried out at pressures of up to 120 pounds per square inch, but in the recovery process it is converted into sodium sulphide; during digestion the sulphide is progressively converted into sodium hydroxide, so that there is always enough but never too great an excess of hydroxide present. The process yields the so-called *sulphate* or *kraft* (meaning "strong") pulp, and it is apparent that the special effect is really due to the sulphide. The ratio of sodium hydroxide to sodium sulphide varies slightly from mill to mill, but unless at least 15 per cent. of the active alkali is present as sulphide the resulting pulp is similar to that obtained by digestion with sodium hydroxide alone.

The sulphate process is generally used for pulping pine and other highly resinous woods, and though it is possible to make an easy-bleaching sulphate pulp, it is used mainly to produce brown kraft pulps for strong wrapping papers. Before the development of multi-stage bleaching processes (Chapter VI) these pulps could not be bleached economically, but to-day various brands of strong bleached sulphate pulps are available. They have a good colour and strength, and have even been used partly to replace rag pulp.

The Caustic Soda Process is used principally for deciduous woods (such as aspen) for printing papers, especially in the United States. A reason for this is that such *soda pulp* produces a soft paper with a high bulk, flatness and good opacity, qualities frequently desired in printing and strongly associated with the use of esparto.

In the United Kingdom there is no mill using the soda or sulphate process on wood, except that, as a war measure, some mills developed the use of *wood waste* (slab wood, or chippings and shavings from wood-working machinery). However, the waste is processed in the digesters normally used for esparto (see Chapter IV). Provided that the wood is cheap, clean and uniform in quality, it is a sound proposition economically.

The recovery of the chemicals in waste sulphate liquor is carried out on similar lines to that used in soda pulp mills (see Chapter IV). However, the roasting stage has to be taken further, in order either to reduce the sulphate present to sulphide or to convert it into carbonate. A disadvantage of the sulphate process is the objectionable smell of the organic sulphur compounds formed during the digestion and the recovery of the soda. A by-product of the process is the resinous *tall oil* which separates from the spent liquor. It is a mixture of resinous and fatty acids, and after purification is a basis for the manufacture of cheap soaps and linoleum.

CHAPTER VI

METHODS OF BLEACHING AND CLEANING PULPS

Mechanical Purification. Screening

Unbleached pulps which have received only washing treatment will contain a proportion of material which should be removed mechanically before the bleaching stage. Thus, wood pulps will contain knots from the original wood and fibre bundles which have not been fully disintegrated. Pulps from esparto may contain roots and other sources of *shive*; and straw pulp residues from the ears as well as pieces remaining from weeds or bean straw, which are more resistant to pulping treatment than are the cereal straws (see Chapter IV).

These contaminating materials should be removed as early as possible in the processing, and by methods which avoid vigorous mechanical handling which might break them down into small fragments, as these are difficult to separate from the rest of the pulp. Further, such incompletely resolved materials consume relatively large amounts of bleaching reagent and still remain lower in colour than the pulp as a whole, and so appear as specks, dirt, or shive in the final paper.

Screens (*Strainers*).—The separation processes employed depend on the differences in the dimensions of the fibre and the material to be rejected, and are described as *coarse screening* (for wood pulps) and *green straining* (for esparto or straw pulp). Since such processes are continuous and follow the discontinuous digestion stage, a storage or buffer chest must be interposed between these stages, in which the pulp can be held (usually at 3–5 per cent. consistency).

For the operation of the screening processes, however, the pulp must have a low consistency, namely 0·5 per cent. or less, and large volumes of water must therefore be added. This water is usually obtained by re-circulating *backwater* or *white water* derived from concentrators and other later stages in the processing (see p 85, and Chapters IX and X). At this stage, too, treatment over sand traps (see p. 83) is sometimes included.

The diluted suspension then flows over screen plates, which are perforated with round holes of $\frac{1}{2}$ to $\frac{3}{16}$ inch in diameter; or long, fine slits down to $\frac{1}{8}$ inch in width may be cut in the plates. Such cuts are usually made wider on the underside, so that any fibre capable of entering the slit is rapidly cleared from beneath it.

The screen plates may be mounted horizontally so as to form the base of a box or trough, and while the stock flows over them they are given a vibrating motion. This assists to align and clear the fibres through the slits, while the larger material is carried forward by the flow of water above the plate, and finally rejected.

Alternatively (Fig. 31) the screen plates may be assembled so as to form the circumference of a cylindrical frame which can be rotated about a horizontal axis. As a rule the dilute pulp is delivered to the inside of this cylinder. The good fibre passes through the openings in the plates and the rejected material flows or is assisted mechanically to the end of the cylinder. If it becomes entangled in the holes and carried up by the rotating screen it is washed into a chute by water jets applied to the outside and acting through the perforations.

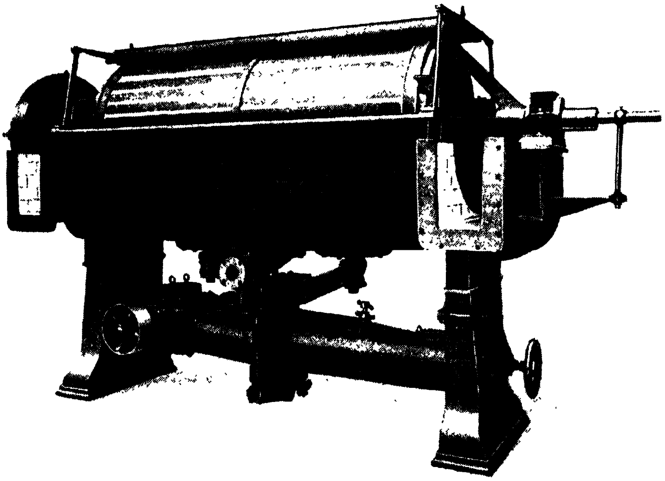

Fig. 31.—Rotary Screen.

It is not unusual for both rotary and flat screens to be arranged so that the rejects from the inside of the rotating cylinder are passed to the flat screens for further treatment. Where maximum cleanliness of the pulp is required it is generally the best practice to remove a relatively large proportion of rejected *knotter* pulp and to re-screen this, rather than to attempt to run coarse screens to close limits.

The amount of rejected material varies according to the raw material and the grade of pulp being produced, namely from 2–6 per cent. for wood pulps or up to 8 per cent. for straw pulps.

Sand Traps (see also above, and p. 115).—The diluted stock next flows over sand traps or *rifflers,* in which material which is heavier than the pulp is removed by settling. The best conditions here are a slow and steady flow in a relatively deep channel, so that the settled material has little tendency to be carried forward with the good pulp. Sand traps are rectangular channels having baffles projecting upwards from the base. The height of the pulp dispersion flowing above these obstructions is controlled by a dam system (B, D), so that any relatively dense particles can settle out and be retained behind the baffles (Fig. 32). This effect can be improved by lining the sand trap with felt or similar material having a rough surface.

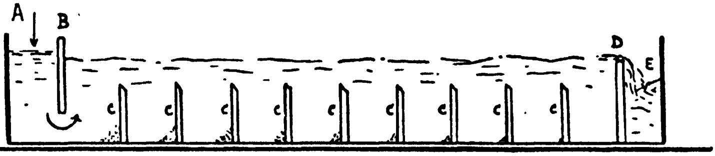

Fig. 32.—SAND TRAP (SECTION).

Chemical Purification. Bleaching

Once the unbleached pulp has been freed from impurities mechanically, it is necessary to use chemical methods to improve the colour and appearance of the pulp. These are *bleaching* treatments, and involve both the oxidation of coloured bodies and the removal of residual incrusting materials (see Chapters III to V) remaining from the digestion and washing processes. In this sense bleaching can be considered as a continuation of the cooking process, and in many modern multi-stage plants no definite distinction can be made between pulping and bleaching, although the mill departments concerned are still given the conventional separate names.

Bleaching Agents and Bleach Requirements.—By far the largest proportion of industrial bleaching methods depend on the use of chlorine or chlorine compounds. The commonest of the latter is *calcium hypochlorite* solution (*bleach liquor*) prepared by extracting *bleaching powder* with water; or alternatively by passing gaseous chlorine into a mixture of lime and water. Such bleach liquor should be given opportunity to settle, so that it is free from suspended bleaching powder residues, lime and other inorganic materials; it is then diluted, so as to contain 2–3 per cent. of *available chlorine,* for use in the mill. The efficiency of such a bleaching agent is generally expressed in terms of the percentage of available chlorine, in the reagent as purchased; thus for bleaching powder it is 35–37 per cent.

The amount of bleaching reagent required by an unbleached pulp is also usually expressed in terms of available chlorine, but calculated as a percentage of the unbleached pulp. It depends principally on the nature of the raw material and, to a less extent, on the final colour required, and it ranges from 0·5 per cent. for high-grade rag to 3–9 per cent. for esparto and straw pulps, according to the cooking treatments they have received (see Chapter IV).

Wood pulps made by the acid (bisulphite) process are broadly classified in terms of their bleach requirements (see Table). Kraft pulps are not usually bleached in paper mills, except possibly the "Light and Strong" grades, and even these will generally undergo only a limited bleaching treatment resulting in a relatively low colour. In mills where kraft pulps are bleached by a multi-stage process (see p. 85), the total available chlorine consumption may range from 7–15 per cent.; together with from 2–4 per cent. of caustic soda, according to the grade and degree of cooking.

The amount of bleaching agent which will be required by the stock is usually assessed by laboratory determinations (especially with purchased unbleached pulps), and recorded in various units known as the *Sieber (Chlorine) Number*, *Roe Number*, *Tingle Number*, *Oestrand Number*, etc. Such tests depend on the reaction of the pulp with chlorine, hypochlorite or permanganate solutions under strictly standardised conditions of time, temperature, and concentration. The translation of these results into mill working conditions necessitates experience with the plant available and a knowledge of the ultimate colour required.

However, the following table gives a general indication of the way in which the Sieber Number is used to classify bisulphite wood pulps according to their bleach requirements.

Bisulphite wood pulp grade	*Range of Sieber Numbers*	*Bleach requirement, as per cent. available chlorine*
Easy bleaching	0·6–1·2	2 –3·5
Bleachable	1·2–1·9	3·5–5·5
Strong bleachable	1·9–2·3	5·5–7·0
Strong	2·3 upwards	7·0 upwards

The Sieber Number is defined as the amount of available chlorine consumed by 100 parts of pulp in 1 hour at 20° C., under specified conditions of concentration and alkalinity. Whilst the above classification applies in most European countries, the chlorine demand of any of the above grades could be increased by at least 10 per cent. for North American practice.

The speed of the reaction between the hypochlorite solution and the colouring or incrusting materials in the pulp is dependent on the concentration, temperature and acidity or alkalinity of the pulp; these variables can be controlled in the paper mill to an extent which depends on the type and capacity of the equipment available. Thus, pulp consistencies of from 5–17 per cent. may be used, and it follows that the pulp must be concentrated after the screening and sand-table processing, either by means of a drum washer (Chapter IV), drum thickener or rotary vacuum filter (p. 89). The bleaching process may be operated either in batches or continuously; and most modern bleaching plants use a combination of both, namely, continuous first stages and batch final stages.

Bleaching Methods.—In its simplest form bleaching is carried out by mixing bleach liquor with the pulp in a breaker or potcher similar to that used for esparto grass (see Chapter IV). Such potchers will circulate pulp at 5–8 per cent. consistency, and vary from the old type of breaker-beater to the more recent installations which use an impeller for circulation in place of a roll. In paper mills these hold about 3 tons of pulp, but the so-called *Bellmer hollanders* used in Scandinavian pulp mills normally hold 5 tons or more.

Where there is insufficient potcher capacity to permit relatively long bleaching times, it is common practice to introduce steam into the potcher to raise the temperature to 30°–35° C.; if, however, steam is admitted in presence of bleach liquor, degradation of the cellulose may result. The bleaching rate may be increased further by the addition of acids or acid salts (such as alum), which incidentally changes the character of the reaction and thereby also increases the likelihood of degradation. Where, however, sufficient capacity exists, bleaching should be carried out under alkaline conditions, as then the reaction is principally that of oxidation and there is much less risk of degradation.

Bleaching in Stages.—With most raw materials 50–75 per cent. of the total available chlorine required will be consumed in 1–2 hours, by which time some of the coloured and incrusting substances will have been dissolved. Since such soluble material will continue to consume bleaching reagent, it follows that economy of the latter, or an improvement in colour for a given consumption of it, can be achieved by an intermediate wash. This was the first and simplest two-stage bleaching process. Thus, about 75 per cent. of the total bleach requirement was added (for instance, in a potcher), followed by a wash, and then the remainder of the available chlorine demand, either in the same vessel or when transferring the pulp to other plant such as a drainer or a tower system.

Potchers (Chapter IV) are usually fitted with one or two drum washers, so that the initial concentration of the pulp and the whole one- or two-stage bleaching process, including the intermediate wash, can be completed in the one piece of plant. Ample potcher capacity must be available, as the cycle of operations takes 8–16 hours.

When insufficient capacity is available in the potchers, the pulp, after circulation with the bleach liquor, may be dropped into drainers (see Rags, Chapter IV) beneath the potchers, and the bleaching action allowed to continue there. Provision should then be made for washing the pulp subsequently, preferably on a special washer, by flooding the pulp in the drainer, or by the use of drum washers on the beaters. Drainers have the disadvantage that the pulp must usually be removed from them laboriously by hand.

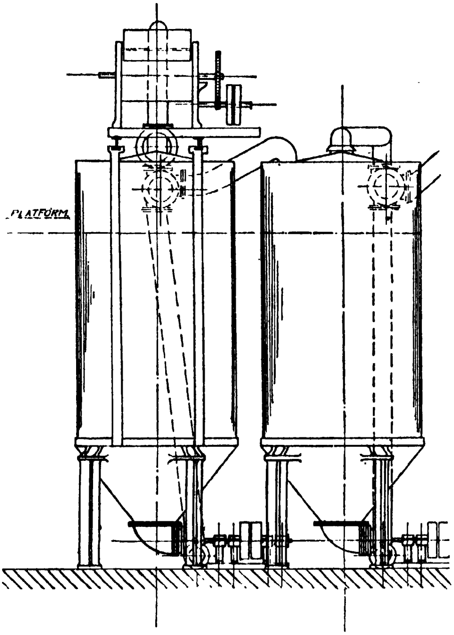

Fig. 33.—Two Bleaching Towers, showing Method of Pump Circulation.

Since the rate of consumption of available chlorine is much lower after the first 1–2 hours, it is usual to circulate the pulp in the potcher during this period only, and then to pump it to vertical cylindrical towers in which the pulp stays for the time required to complete bleaching. Such towers are also often arranged (in series) to receive the pulp directly from the potcher immediately after it is mixed with the bleach liquor; and pumps pass it on from tower to tower. Further, there may be facilities for recirculating through one or more of the towers should the bleaching be incomplete (Fig. 33).

With the recognition that chlorine combines selectively with lignin (the principal incrusting material remaining on most unbleached fibres), it was apparent that chlorine, as such, should be used for the first stage of bleaching, particularly of wood pulps. This was, in a sense, a return to the earliest bleaching practice in paper mills, where chlorine gas was admitted to sealed, lead-lined rooms containing layers of the moist pulp. Such methods obviously are not practical for large wood-pulp mills, and the bulk use of chlorine had to await the production of acid-resistant bleaching plants before it could come into general use. However, as soon as rubber-covered equipment and acid-resistant washers became commercially practicable, the one- and two-stage hypochlorite bleaching processes in pulp mills were rapidly replaced by multi-stage processing methods, involving *chlorination* first on batch lines and then continuously.

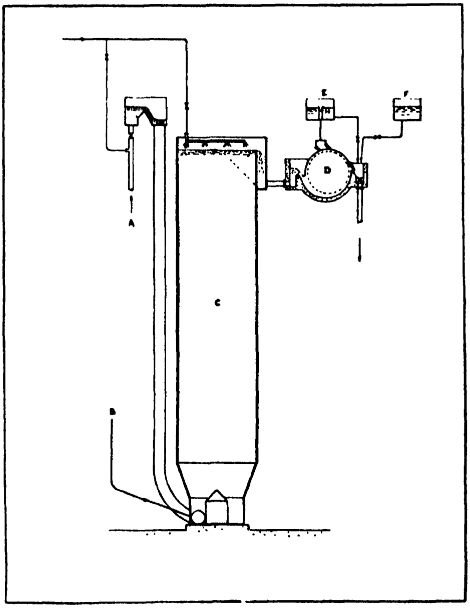

Fig. 34.—Chlorination Tower with Washer.

For the chlorination stage, pulp at 3–5 per cent. consistency is pumped in at the base of a tower 50–60 feet high (C, Fig. 34) and chlorine is introduced in gaseous form, as a solution in water or as an emulsion of liquid chlorine in water under pressure, at B. The chlorine rapidly reacts with the lignin residues in the pulp and converts them to water-soluble or alkali-soluble compounds, producing hydrochloric acid as a by-product. It is because of the corrosive properties of the chlorine and this acid that special resistant equipment must be used for this stage. If only 50 per cent. of the total available chlorine demand of the pulp is added, the pulp rising in the tower will contain no free chlorine after a few minutes; with wood pulps total chlorination times of less than 30 minutes are quite usual and 1 hour is the normal maximum.

The acid liquor may now be removed by passing the pulp overflowing at the top of the tower over a washer (D) of the usual wire-covered drum type, but made of acid-resisting material. In early plants the corrosion difficulty was avoided by adding alkali (such as lime or caustic soda) in excess, and the pulp could then be washed in the alkaline condition on standard equipment. This method has a number of defects, notably the high cost of the alkali, and it has now been largely superseded by washing the pulp in the acid state.

To dissolve out all the chlorinated lignin it is necessary not only to make the mass alkaline (F), but also to allow time for the soluble materials to diffuse out of the fibre; extraction is accelerated by heating the pulp. To conserve steam and maintain an effective concentration of alkali, the pulp consistency is kept as high as possible (up to 17 per cent.) by the use of press rolls on the filter or washing drum used after the chlorination stage. The pulp is again washed to remove the alkali-soluble chlorinated compounds; it then passes to the continuous, high-density bleaching stages or to a bleaching potcher.

Obviously such processing can be further elaborated to suit the particular requirements of a given raw material. For instance, where maximum strength retention is desired from difficultly bleachable material (such as strong kraft pulp), the risk of degradation occurring under the acid conditions of the first stage may be reduced by using two chlorination stages with an intermediate wash. Treatment with alkali at 50°–90° C. would then follow, and after further washing the pulp would receive hypochlorite bleaching in one or two stages, one of which might be continuous and the other batch. Similarly, hypochlorite treatment before chlorination has been found advantageous for some types of pulp. Obviously, a variety of processing methods can be operated with these continuous tower systems.

The old type of drum washer removes only a small proportion of the liquor at a time, and therefore takes a very long time to complete the washing. The efficiency of multi-stage bleaching processes, therefore, depends on the use of washers of the concentrator or rotary vacuum-filter type (Fig. 35), on which the pulp may be concentrated to 15 per cent. or more before either passing under washing sprays or being again diluted. In many plants, also, provision is made for keeping the pulp in water for some time, so that the soluble products of the bleaching reaction can diffuse from the fibre into the liquor (which is later removed). This improves considerably the colour stability of the pulp and the paper made from it.

Where insufficient water or inadequate plant is available for thorough washing, chemicals known as *antichlors* may be added at the end of the bleaching process; these combine with and so destroy the residual bleaching agent. This practice is costly and has been largely superseded by effective washing installations, although sodium thiosulphate ("*hypo*") is still used for this purpose in some paper mills. In wood-pulp bleaching plants the recent trend is to return to the use of sulphur dioxide, which can be regarded as an antichlor, although its purpose is now rather to reduce the ash content of the pulp (see also p. 114).

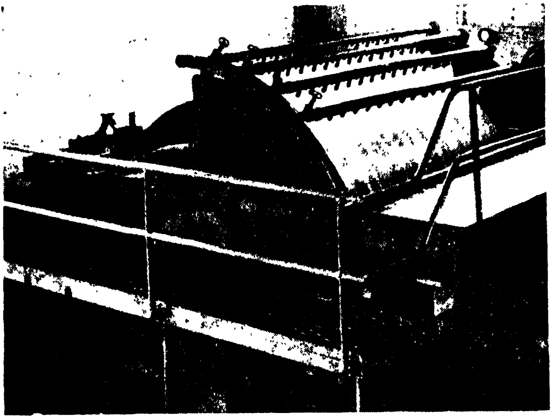

Fig. 35.—Rotary Vacuum Filter.

Recent Bleaching Methods.—Recent developments in the use of chlorites and chlorine dioxide for bleaching pulp have shown that, although relatively expensive and requiring special plant, these reagents have a definite advantage in that they cause less degradation of the fibre. For cost reasons the use of chlorine dioxide has so far been restricted to a final processing in multi-stage bleaching. However, this is the stage at which degradation is most likely to occur when ordinary bleaching reagents are used to obtain a high-white colour, and the use of chlorites or chlorine dioxide has made it possible for sulphate pulps to be brought to the colour of bleached sulphite grades with only a slight loss of strength. Further, such chlorine dioxide-bleached pulps are said to show less yellowing on exposure to light than are the equivalent hypochlorite-bleached grades; this is a matter of importance, especially with bleached sulphate pulps.

Mechanical wood pulps may be improved in colour within a limited range, but such bleaching is usually carried out in the pulp mill rather than in the paper plant. Since mechanical wood pulp contains the whole of the lignin-incrusting material of the wood and since chlorine is known to combine selectively with lignin, it follows that if chlorine-type bleaching reagents are used very large quantities will be required to combine with all the lignin present; this would virtually convert the mechanical wood pulp into chemical wood pulp. The bleaching reagents used must therefore depend on an active principle other than chlorine. Reducing agents (such as hydrosulphites) and oxidising agents (such as the recently advocated sodium peroxide) are relatively expensive and therefore have found limited uses for bleaching mechanical wood pulps.

Screening Bleached Pulp.—With the trend towards bleaching in the pulp mills instead of in the paper mills there has been increased demand for clean pulps, and it is now general practice to use another screening stage after bleaching and washing The procedure is usually one of the methods already described for coarse screening, including, possibly, sand-trap treatment, but flat screens with fine cut that may go down to 0·01 inch in width are frequently used.

Obviously such flat (or *diaphragm*) screens depend on the effect of gravity to bring the fibres down through the suspension and through the slits, and this effect can be aided by making use of centrifugal action in either horizontal or vertical cylindrical screens. Stock consistencies are usually lower than for coarse screening (p. 81); they depend on the type of screening plant and may be as low as 0·15 per cent. The great dilution required to produce this is, in a sense, a washing stage, but few mills can afford to use all fresh water for the purpose, and some recirculated white water (p. 130) is generally employed. The stock may be further cleaned by applying centrifugal action to it at low consistency, but without screening plates. The difference in density between the dirt and fibres causes them to separate. Centrifugal action is produced by rotation at a high speed or by giving the fibre suspension a rotary vortex motion by a tangential injection device (see p. 115 for fuller details).

When the pulp is to be made into paper in the same mill as that in which it is prepared, it is very conveniently pumped in the wet (*slush*) state to the beater house of the paper mill. Alternatively, it is partly dewatered (so as to contain 25–30 per cent. of pulp) by passing it over a presse-pate which is, as a rule, a simple Fourdrinier paper machine wire part (as described in Chapter IX), sometimes with a couch and even a press. This delivers the pulp as a thick, wet web, which is formed into *laps* and stored in this state until required in the beater house. The *wet press* (used principally for chemical wood pulp) achieves the same object by removing water from the dilute pulp through a wire-covered drum rotating in a vat into which the pulp flows; the wire picks up the pulp, which is removed from it as a continuous web, passed through press rolls and cut into laps.

If the pulp has to be sent away it is usually necessary to remove all but about 10 per cent. of the water; it is then run from the presse-pate, through presses, and over drying cylinders. The process is therefore very similar to that of paper manufacture, except that the refinements of the paper machine are unnecessary. Pulp loses certain of its characteristics (and especially some of its strength) as a result of drying. In consequence, some pulps (particularly mechanical wood pulps) are despatched containing a certain amount of moisture (about 50 per cent.), and this despite the extra carriage charges and risk of mildew formation.

CHAPTER VII

THE BEATER HOUSE—BEATING

Methods of Defibering Pulps

THE PULP obtained by the methods described in Chapters IV, V and VI is now ready for the first step in the actual paper-making process; this is the separation of all the fibres from one another. The rag fibres after boiling and washing are still largely in the form of woven fabric. The fibres of wood pulp used in the form of moist or dry thick sheets will be matted together. Even esparto and straw pulps retain the shape and form of the original grass stems until they are bleached. The separation of the fibres of the pulp is known as *breaking* or *defibering*, and is effected in machines known as *breakers* or *potchers*.

Rag fibres which are woven into fabrics require a fairly drastic and prolonged breaking treatment, whilst moist wood pulp sheets respond to a milder treatment. Dry wood pulp sheets, especially dry kraft or strong sulphite pulps, are more difficult to break, though less so than rags. Esparto and straw are usually broken up easily during the final washing and bleaching.

The special equipment used for rags, esparto and straw is dealt with in Chapter IV. Reference to this chapter will make clear the essential difference between the breaker and the beater (described below). Wood pulp received at the mill must nevertheless be defibered, and methods of doing this will now be discussed.

Wood Pulp Breakers.—The rag breaker could be used for defibering wood pulp, but for economy other methods are often used; they do not give such complete defibering, but are adequate for most purposes. An example is the breaker used for defibering the newsprint furnish, consisting of 25 per cent. unbleached sulphite and 75 per cent. mechanical wood pulps. Since these pulps are easily defibered by violent agitation, such breakers consist only of a trough and a barred roll; there is no bedplate. The bars are thick, and their faces usually have a wavy pattern. As the roll revolves the mixture of pulp and water is propelled round the trough and the pulp is broken up.

The clearance between the roll bars and the bottom of the trough is fixed at about 6 inches, so that the sheets of wood pulp can be fed into the breaker in thick wads, thus speeding up the process. Any incomplete defibering can be rectified at a later stage in the actual beater.

Pulpers.—Pulps such as dry kraft or waste papers are more difficult to break up, and the defibering process is usually carried out at a high consistency in a pulper. Defibering is incomplete, but it is sufficient for most purposes.

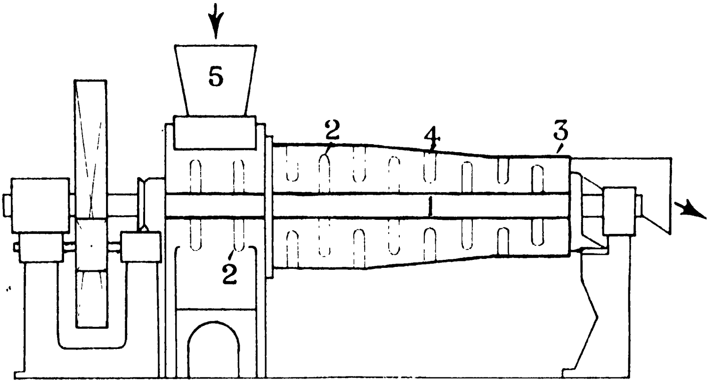

Fig. 36.—Pulper.

In the usual form of pulper (Fig. 36) a shaft (1) carrying curved teeth or arms (2) revolves in a conical or cylindrical casing (3), also provided internally with stationary arms (4), between which the

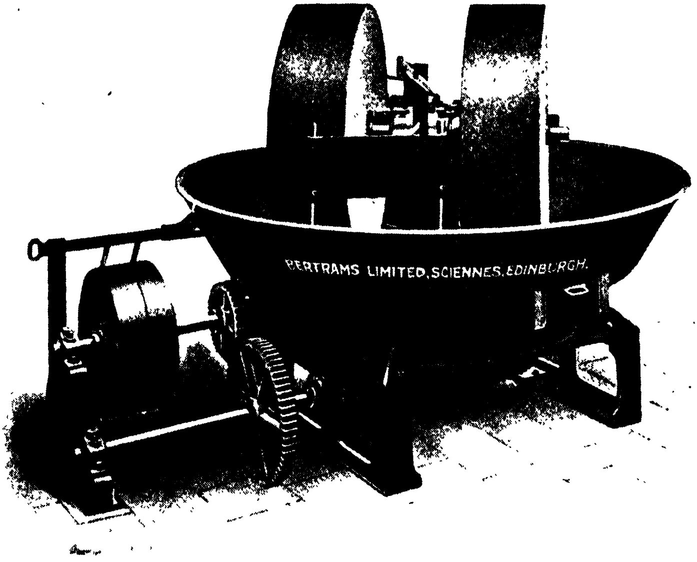

Fig. 37.—Kollergang.

moving arms revolve. The pulp sheets are fed into the hopper (5) with a continuous stream of warm water at about 90° F. (32° C.) and the pulp emerges from the other end, fairly well broken-up, at a consistency of 15–20 per cent.

Kollergangs (Fig. 37) are frequently used to defibre pulp and waste papers; they operate on the principle of the edge-runner or mortar mill. Two revolving iron or stone grinding rollers travel round a circular pan containing the material to be treated, with only a little moisture, and the method is both effective and economical. Resistant types of waste papers are sometimes given a preliminary cook in a rotary boiler of the type used for rags (p. 54).

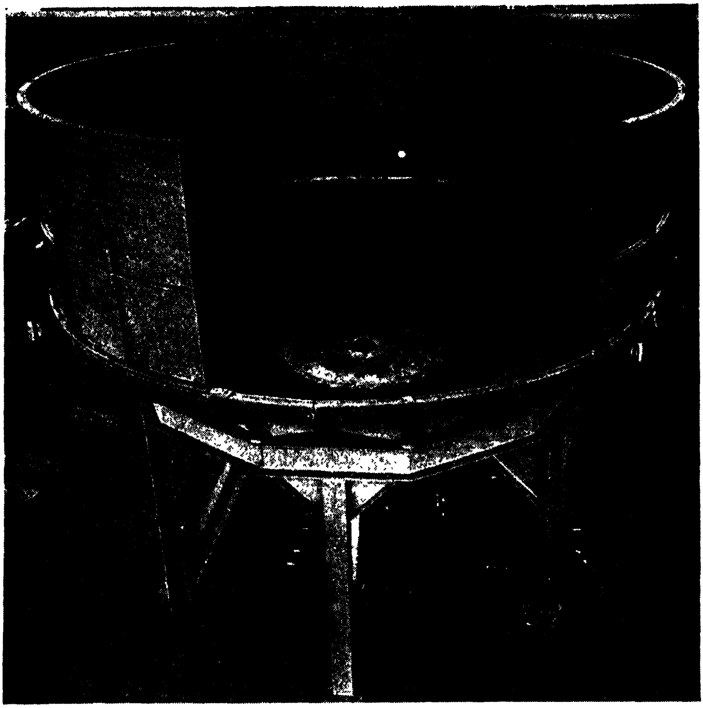

Fig. 38.—Hydrapulper, showing Rotating Base.

Hydrapulper.—This modern method of defibering uses a large cup-shaped vessel having at the bottom a propeller running at a very high speed. This throws the pulp and water suspension towards and up the sides; it then falls down the centre towards the propeller again (Fig. 38). This high-speed swirling can break up not only sheets of pulp or waste papers but also whole bales. Some models are equipped with a device for removing continuously wires, strings, rags, etc. (*trash*) from low-grade waste papers.

The defibred pulp, ready for the beater, is known as *half-stuff*.

Beaters

Since the hollander beater was invented (see Chapter I) the principle of the beater has remained substantially the same. It consists of a barred roll revolving over a stationary barred *bedplate*. The pulp suspension passes between the moving and stationary bars, round a trough, and between the bars again. This circulation is continued until the pulp is ready to be made into the paper desired.

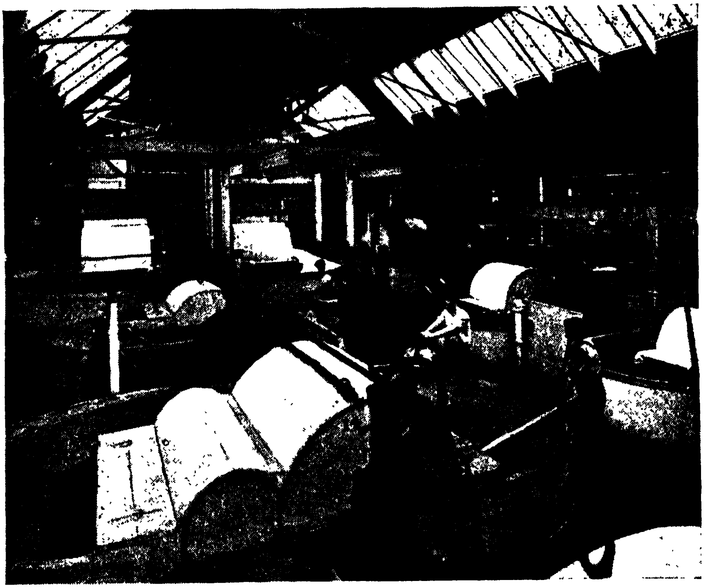

Fig. 39.—Beater House. General View.

Hollander beaters are shown in Fig. 39, and are similar in general design to the breaker or potcher described in Chapter IV (Figs. 18 and 19). However, they have no drum washers and the bars on the roll are spaced differently. Moreover, since in beating it is necessary to control the relative positions of the roll and bedplate more accurately than in breaking, the mechanism for lowering and raising the roll must have accurate adjustments, enabling a clearance of up to ½ inch to be obtained between the roll and the bedplate; otherwise even a very skilled beaterman will not be able to beat his stuff satisfactorily. The peripheral speed of the beater roll also is greater than that of the breaker, being 1,900–2,000 feet per minute. The weight of the roll and the dimensions, material, number and spacings of the bars in it and in the bedplate vary according to the types of paper to be produced.

The principle of the *Umpherston* beater is similar, but after it has passed under the roll the stuff continues under the floor of the trough of the beater, and comes up again on the inlet side of the roll for further treatment. Floor-space is thus saved.

In the *Bertram Patent* beater (Fig. 40) the bedplate is not vertically under the roll, as in the hollander, but is nearer the *backfall.* Similarly with the *Voith* beater, the bedplate of which is in such a position that a line from its centre point through the shaft of the roll is 45° from the vertical.

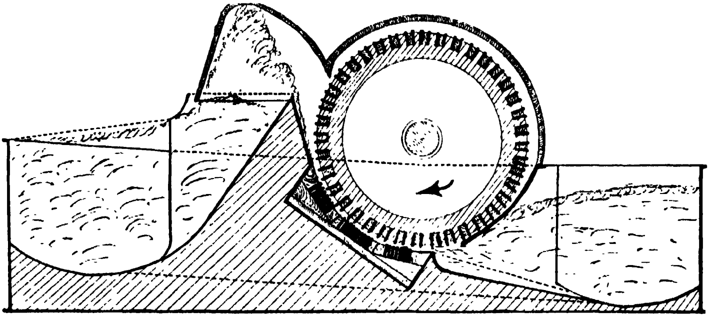

Fig. 40.—Bertram Patent Beater.

The *Thorsen-Héry* beater differs again in that, first, the roll revolves on a fixed axis on a shaft with fixed bearings, in the opposite direction to the flow of the stuff (which is thrown over the roll). Secondly, it is the bedplate which is adjustable, and this is placed on the side of the roll on to which the stuff flows. In other types of beater, circulation by means of a pump is used.

The capacity of a beater usually ranges from 200 to 500 pounds in the case of rags, to 1 ton for wood pulp, and the roll can weigh as much as 10 tons.

The Beating Operation.—After the breaking process the desired mixture of rags, wood, esparto, or straw half-stuffs (the *furnish*) is passed into the beater and brought to a consistency usually of 5–7 per cent.

The quality and characteristics of the finished paper depend to a great extent on the treatment in the beater, and this can be controlled so as to produce papers as widely different as a blotting and a greaseproof. The beaterman's task, therefore, is one of the most important in the paper-making process. He has, first, to consider the type of fibre he is using, because various fibres respond differently to beating; and, secondly, the type of paper to be made, so that he can decide on the beating conditions. The variable factors include the pulp consistency, the material and thickness of the bars in the roll and bedplate, and the extent and rate of alteration of the clearance between the roll and bedplate bars. The weight of the roll plus the pressure applied determines the clearance between the bars, and it can be controlled by the power consumption reading in the case of an electrically driven beater.

If the beater is driven from the main shaft, it is the beaterman's judgment and experience which mainly control the beating. He is, however, aided by laboratory tests (see p. 185) of the readiness of the pulp to part with its water by drainage. Thus, in the *Canadian Freeness Test* the diluted pulp is allowed to drain under standard conditions through a sieve. The resulting drainage water passes to waste through a small hole, and the water over a certain level above it is taken off through an overflow and measured in a glass cylinder. The *Schopper-Riegler Test* is similar in principle, but the measuring cylinder is graduated with 0 at the *top*. A *wet* pulp therefore gives a high Schopper-Riegler and a low Canadian Freeness value; and vice versa.

To a considerable extent the difference between papers made from different fibres depends on the dimensions and shapes of the fibres (see Chapter III). Some knowledge of the structure of the fibre is necessary in order to understand what happens to it in the beater. The fibre as seen under the microscope (see Chapter III) is a tube- or ribbon-shaped object of very small dimensions, composed of cellulose and allied substances. The cellulose, however, is in the form of extremely fine threads, which are not visible under the ordinary microscope. These threads are bundled and bonded together in what are known as *fibrillae*, and it is aggregates of these which form the complete fibre. A fibre, therefore, may be likened to a short piece of stiff, thick rope, the fine threads being bundled together to form strands, which in turn are aggregated to form the rope.

Paper-making fibres are stiff and springy, and if they are made into a sheet of paper without beating the resulting paper will be flabby and weak. There will be little adhesion between the fibres and they could not be consolidated under the presses of the paper machine (Chapters IX and X). At the beginning of the beating process the clearance between the roll bars and the bedplate bars is large in comparison with the thickness of the fibre. During this *brushing-out* period the half-stuff, if it is not already completely broken up, is thoroughly defibred; and because of the violent agitation in the presence of water, the fibre itself becomes more flexible and plastic and the fibrillae become looser inside the fibre, so that what may be described as "internal" fibrillation occurs. There is also evidence that the fibres as a whole swell to some extent at this stage.

The roll is now lowered towards the bedplate, and as the clearance decreases to a few thousandths of an inch, the fibres caught between the bars are crushed, bruised and cut. Some fibrillae are torn away from the fibre, while some are ruptured but remain joined together at one end ("external" fibrillation). Each time the stuff travels under the roll more fibres are treated, more fibrillae are produced and more fibres are shortened; and this increasing state of subdivision causes the stuff to feel greasy and slippery, or as the paper maker terms it, *wet* (or *slow*, or *hydrated*). He means that, because the fibres have become flexible, fibrillated and shortened, the closer mat which they will form on the wire of the paper machine will not allow the water to drain through so freely. The opposite state to wet, therefore, is termed *free*. Wet-beaten fibres are held in suspension on the wire for a longer time, so that the shake (see Chapter IX) has a better chance of arranging them to form a close and even sheet of paper.

A close sheet cannot, therefore, be made if the fibres are too long and free. The suitable range of length of fibres for existing paper machines is about 0·02–0·12 inch. This means that with (say) cotton fibres up to 0·8 inch long, special attention must be paid to cutting as well as to fibrillation in the beater. The shortening of the wood pulp fibres incidental to beating is sufficient to bring the fibre length into the above range; straw and esparto fibres are short enough to start with. If stiff and springy unbeaten fibres are made into a sheet of paper, this will be weak, flabby and bulky, with a "wild" look-through, especially if the fibres are long. When they are beaten (that is, fibrillated internally and externally) and shortened we then have a mixture of flexible fibres, shortened fibres, fibres which are fibrillated along their outer surface, detached fibrillae and fibre débris, which settles on the paper machine wire into a consolidated mat with the longer fibres intertwined and the shorter fibres and fibrillae filling the spaces between. Numerous fibre-to-fibre contacts are thus made, and on drying these are bonded closely together. Further, the fibrillated fibre is rougher than the unbeaten fibre and therefore does not slip so easily. The result is a strong, firm sheet of paper.

The three photomicrographs, Figs. 41, 42 and 43, show, respectively, chemical wood pulp unbeaten, beaten to make into an average paper and beaten for a greaseproof paper. Fig. 42 shows fibrillae produced as a result of beating, and a comparison with Fig. 41 demonstrates that some of the fibres have been shortened. Fig. 43 depicts an extreme degree of beating, resulting in many fibrillae and short fibres.

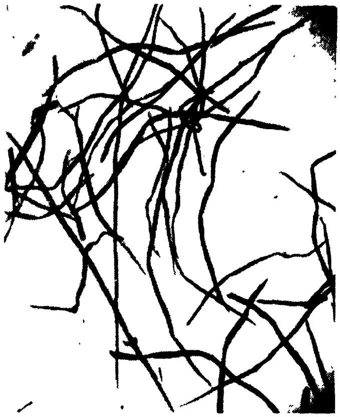

Fig. 41.—Wood Pulp Fibres. Unbeaten.

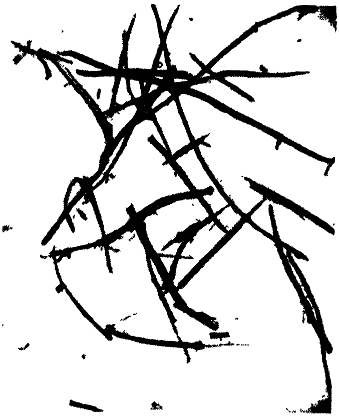

Fig. 42.—Wood Pulp Fibres. Moderately Beaten.

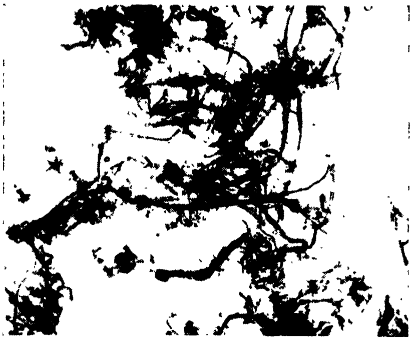

Fig. 43.—Wood Pulp Fibres. Well Beaten.

The substance or weight of the sheet of paper to be made and the speed at which the paper machine is running determine, to a great degree, the time of beating. The stuff for thick or heavy papers must not be beaten too wet, otherwise great difficulty will be experienced in removing the water from it on the paper machine and consequently in maintaining output. On the other hand, the stuff for thin papers may be beaten relatively wet. However, if the stuff is not beaten sufficiently the water will drain away too quickly and a badly formed sheet of paper results. The beaterman must bear all these points in mind. As already stated, different classes of fibres respond differently to beating. Thus for strong papers it is necessary to have fibres which will fibrillate easily and can be beaten wet (such as the bast fibres, rag, kraft and unbleached sulphite wood pulps used for making ledgers, banks, wrappings and bag papers). Also the roll and bedplate bars must be not less than ¼ inch thick and must be made of a metal which will not become sharp on the edge, so that fibrillation will take place without excessive cutting of the fibre.

So far we have been discussing mainly wet beating to produce strong papers. Now greaseproof paper is not necessarily strong, but the pulp (unbleached sulphite wood) from which it is usually made is beaten wet, as for strong papers, the process being taken to extremes, for instance, by the use of a lava-stone roll. The stuff is beaten almost to a jelly (see p. 98) and is, therefore, very reluctant to part with its water. This means that the paper machine has to run more slowly than it does for ordinary papers, but that the sheet produced is very dense and all the small spaces are filled, thus preventing the easy passage of grease.

For the opposite reason, pulp for papers which have absorbency towards liquids is beaten free. Wood pulp for, say, towel paper is beaten only very lightly so that the fibres are springy, forming a bulky, loose sheet of paper with the maximum spaces between the fibres into which the water can rapidly flow. The towel paper so produced would, however, disintegrate easily when soaked with water, just as blotting paper does. To prevent this, a small amount of synthetic resin is often added to the stuff in the beater; the fibre contacts do not then come apart easily in the presence of water, and yet the absorbency of the paper is not affected. Blotting paper made from rags is another example of free beating; it has to be very absorbent (to ink), but as it does not undergo complete soaking in the liquid, the treatment with resin is unnecessary.

Effects of Beating on Different Fibres.—*Rag fibres,* as we know, are long and must be cut to produce a close sheet of paper. They are also very easily fibrillated, but the presence of fibrillae is undesirable in a paper that has to be absorbent. Thus, in the preparation of rag half-stuff for blotting paper, cutting with minimum fibrillation is achieved by using sharp narrow bars in the beater roll and bedplate, by having a very small clearance between them from the start of beating, and by working at a low consistency. The time in the beaters is usually short, about 30 minutes, as compared with the 8 hours or more required to beat rags for strong papers.

With imitation art and magazine papers, wood-free and mechanical printings, and newsprint, printing quality is of primary importance. This depends to a considerable extent on the types of fibre used, and the better grades are made from bleached sulphite pulp, either alone or mixed with esparto and sometimes straw pulps. These give a close, uniform sheet, with a good even surface which is receptive to printing ink. Esparto contributes bulk, opacity and flatness.

Esparto and *straw* are short-fibred pulps, which do not fibrillate like rag or strong chemical pulp fibres; in any case, a high strength is not required of them. Consequently the main objective when beating these pulps for printing papers is to defibre them completely and to avoid too much cutting. The bars of the roll and bedplate need not be thick (as for wet beating), but it is more important that they are made of metals such as bronze or stainless steel that do not corrode, because the paper must be clean as well as white. Extra precautions taken for the sake of cleanliness are tiled-lined beaters and chests. Under the same beating conditions, however, straw wets up more rapidly than does esparto, and the resulting paper has a lower bulk, greater transparency, bursting strength and hardness (*rattle*), and a poorer tear. The differences between these two fibres are further emphasised on p. 47, and it should be borne in mind that marked differences do exist, even though straw was used as a substitute for esparto owing to war-time conditions.

The *bleached sulphite fibre* does not lend itself well to fibrillation. This may sound contradictory after the statement that strong wrappings and greaseproofs are made from wet beaten unbleached sulphite, and the explanation is as follows. As previously mentioned, the wood fibre after cooking consists of pure cellulose with related cellulosic materials in quantities depending on the cooking conditions (see Chapter V). A long time in the digester and purification by bleaching (especially to produce a very white colour) remove the latter, leaving a relatively high proportion of pure cellulose. The resulting fibre is more brittle, so that it will break rather than fibrillate, and therefore it is suitable for making into the well-formed, close sheet required for a printing paper. Bamboo, chestnut and eucalyptus soda-pulps are all short fibred, and are suitable for printings (see Chapters II and III).

The cheapest printing paper is *newsprint*, which is made from a mixture of about 75 per cent. mechanical wood pulp and 25 per cent. unbleached sulphite wood pulp. The mechanical wood (see Chapter V) is short-fibred, with a large proportion of fibre débris or *flour*, and it has relatively little strength, especially as a wet web on the paper machine. Hence the addition of the longer-fibred *unbleached sulphite pulp, which gives a framework to the sheet.* The pulp is defibred fairly completely in a newsprint breaker, and then passed through a refiner (see below) to disintegrate (*clear*) any bundles of fibres which the breaker has not dealt with; it is then ready for the paper machine. Water is removed relatively easily from free stuff, an important point, since newsprint machine speeds are much higher (up to 1,400 feet per minute) than for other types of paper.

Refiners

In newsprint mills and mills having fast-running machines a *refiner* is used to complete the brief beating operation, because the furnish is broken up in a breaker and the defibering is not necessarily complete. In such cases the stuff is diluted to about 3 per cent. consistency and pumped continuously through one or more refiners, where any bundles of fibres are cleared. Newsprint requires little or no beating, and the stuff can be adequately prepared by breaking and then pumping through one or more refiners, according to the rate at which the stuff has to be prepared.

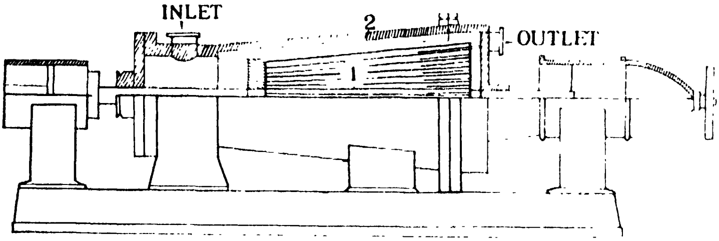

Fig. 44.—Cone Refiner.

A common type of refiner (Fig. 44) consists of a cone (1) fitted with longitudinal bars, similarly to a beater roll, and revolving in a conical shell (2) having similar bars. It therefore behaves rather like a beater roll with a bedplate all round it. The cone is adjustable longitudinally, so that the clearance between the two sets of bars can be set according to requirements. For newsprint pulp, which needs to be little more than defibred, a wide clearance is used. The mean peripheral speed (up to 2,500 feet per minute) is higher than that of the beater roll. By reducing the clearance between the bars of the cone and the shell to a few thousandths of an inch, a considerable degree of beating can be achieved by one passage of the stuff through. The refiner can therefore be used to supplement the beaters.

In the *disc refiner* the pulp is passed, with a radial motion, between a vertical rotating disc and a stationary disc on each side of it. The beating action takes place between the fixed and stationary bladed surfaces, the distances apart of which can be varied. Combinations of cone and disc refiners also exist, in which the rotating disc is fixed to the outlet end of the cone.

A battery of beaters, even of the same make, cannot be guaranteed to produce stuff having exactly the same degree of wetness, even with the same conditions of beating, such as time and consistency. The resulting fluctuations are levelled out somewhat in the beater chest, where two, three or more beater charges are mixed after beating. However, passage through a refiner controls the degree of wetness before the stuff finally goes to the paper machine, thus ensuring even running on the latter.

In large mills with fast running machines the refiner is an integral part of the beating plant. The stuff is circulated continuously through a battery of refiners, and if high pressures are used the beating effect is equivalent to that produced by a beater in 1–2 hours. Thus refiners render fewer beaters necessary, and so there is a saving in floor space. Nowadays, refiners are by no means restricted to newsprint and similar mills. They supplement the beaters in many types of mill, and to an extent which depends on the importance of controlled beating in the manufacture of the mill's products. Thus they play a relatively minor part, as compared with the beaters, in a mill making fine papers, since such papers require a degree of controlled beating obtainable only with the latter.

CHAPTER VIII

THE BEATER HOUSE—AUXILIARY OPERATIONS

THE PAPER maker's beater is a convenient vessel to which materials can be added and intimately mixed with the pulp, in order to give special properties to the final paper. The action of the beater roll assists this by so-called *beating-in.* The main drawback to the method is that a proportion of the materials added may be lost through the wire cloth of the paper machine with the large amount of water used. Because of this, chemicals which remain in solution cannot be used; they must be thrown out of solution (*precipitated*) in the solid state, so that they are retained among the fibres to the maximum extent.

Mineral loading materials, sizing agents and starch in its various forms are all usually added to the beater, as well as special chemicals, such as those used to prevent the forgery of cheques; and the addition of dyes or pigments to tint or colour the paper is usually best carried out at this stage.

Engine Sizing

If paper is made from pure beaten fibre without any additions, it will be absorbent (rather like a blotting paper) to an extent which varies according to the nature of the fibre and the kind and amount of beating it has received. Writing ink will penetrate and spread through such a paper, and to prevent this certain chemical substances are added. This operation is called *sizing,* and when it is performed in the beating engine it is called *engine sizing.*

By far the most widely used materials for engine sizing are rosin and alum. Rosin, distributed in small particles on the surfaces of fibres, renders the papers made from them less readily wetted by water. It is also convenient to use, as a solution can easily be made by boiling it with an alkali, or it can be dispersed in fine particles in water so that it is readily distributed throughout the pulp. When this is done, alum (p. 107) is added to the pulp to precipitate the rosin, so that most of it is retained by the pulp on the wire of the paper machine. Although these operations appear simple, the correct procedure is important.

Rosin (Colophony) is a yellow or brown, glassy, brittle substance obtained from pine-trees. When bark is chipped the gum or *resin* which oozes out is collected (Fig. 45) and distilled with water. Turpentine is driven off and rosin is left in the still. Rosin is also obtained by heating the pine chips with steam and then dissolving out the rosin in a solvent; it is then reddish in colour (*wood rosin*). Rosins are graded according to colour, and are identified by letters of the alphabet, in order; the darkest, which are almost black, occur at the beginning the palest being W–G, W–W and X. The best all-round grades for sizing paper are F and G, as they are fairly pale in colour and are also sufficiently hard.

Rosin cannot, of course, be dissolved in water, but being acidic in chemical character it can be neutralised and dissolved by solutions of caustic soda or carbonate of soda (*soda ash*). Its principal constituent is *abietic acid*, which combines with the alkali to form a *soap;* in fact, rosin is often used, as such, in yellow soaps. Although some rosin soaps are made in which practically all the rosin is neutralised (*saponified*) by alkali, giving a light brown solution, it is possible to restrict the amount of alkali used so as to leave some of the rosin unneutralised ("free" rosin). Under certain conditions the free rosin will disperse into very small particles, giving the diluted size the appearance of milk ("white" or "acid" size). Care must be taken in the manufacture and dilution to prevent the rosin particles collecting together to form spots in the sheet.

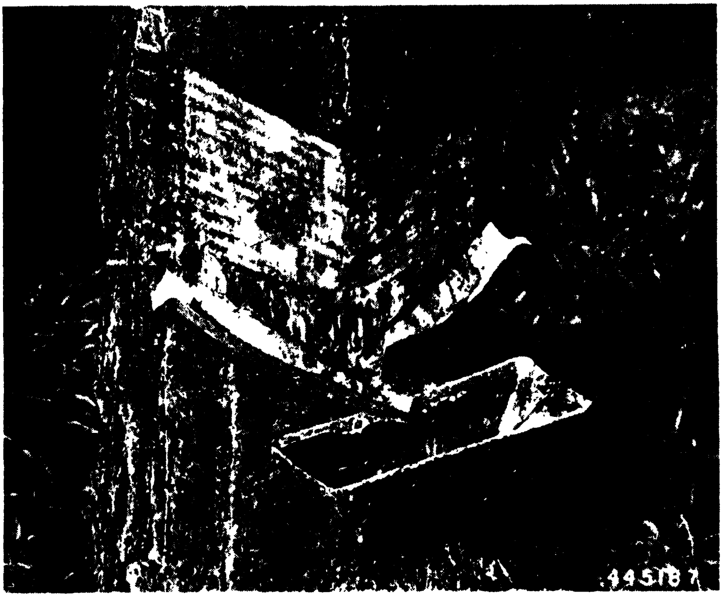

Fig. 45.—Collecting Rosin from a Pine.

Rosin soap sizes are usually made in vertical cylindrical boilers containing the soda solution, to which the coarsely powdered rosin is added carefully, but not too slowly. About 3 hours of boiling are necessary for processing 1–2 tons of rosin for a neutral size, and about 7 hours for an acid size to ensure that the reaction is complete. For a neutral size, the proportions of soda and rosin should be about 1 : 6, the exact ratio depending on the type of rosin used. An acid size requires 11–12 per cent. of soda ash on the weight of rosin to keep about 30 per cent. of the rosin in the free state.

Some special brands of rosin size are made by patented methods. Thus, Delthirna size is made by running cold caustic soda solution through U-shaped tubes containing lumps of broken rosin. The rosin dissolves, giving an easily used brown size of constant composition. Quite different is Bewoid size, which consists almost entirely of free rosin, dispersed by special methods to give a clean white cream, which is specially suitable for direct addition to the beater. As no alkali is present, it requires a minimum of alum for its precipitation, although further amounts are often necessary to ensure adequate sizing. Special Bewoid sizes containing mineral loadings are also available.

Waxes are also used in some sizes, with or without rosin, particularly where high water-resistance is required (as in a wrapping paper). These sizes must be used carefully, to avoid wax spots. Other sizes make use of residues from petroleum distillation, called *petroleum resins.* These are dark brown, and although they can be used to produce pale brown emulsions, they are suitable mainly for sizing papers which are not white in colour. War-time substitutes for rosin included soap and naphthenic acids.

To obtain a paper which remains strong when wet, it is necessary to use a *synthetic resin* for sizing. Such resins are usually made from urea and formaldehyde or from melamine and formaldehyde, and their use is becoming widespread for such papers as wrappings, paper towels and map papers (see p. 33). However, they are not sizing agents in the sense that rosin is, as they do not increase the water-repellent properties of paper.

Rosin Size in the Mill.—Although dry, powdered rosin soap sizes are obtainable, it is almost universal practice to market prepared sizes as a thick treacle containing up to 75 per cent. of solid matter. These are frequently added to the beater as received, but with the finer grades of paper it is preferable to dilute the treacle to a solution containing 4–10 per cent. of solids, which can be put through a strainer to remove dirt and coarse particles.

Neutral (brown) sizes can be diluted easily, even with cold water; but the more rosin present in the free state, the more care must be taken with the dilution. If more than 35 per cent. of the rosin is "free," the dilution must be made slowly with hot water with violent agitation; or by blowing the treacle into hot water through a steam injector. Even then on standing the rosin may separate. If possible, soft water (such as steam condensate) should be used for dilution, to avoid the formation of scum caused by interaction with the calcium salts in hard water.

The amount of size to be used depends on many factors. In general, to obtain *hard sizing* under almost all conditions, up to 4 per cent. of rosin (calculated on the dry fibre) is required. This would apply to boxboard and to certain papers for subsequent coating, such as blueprint papers. Most writings and sulphite pulp wrappings require 2–3 per cent.; and printing papers and kraft pulp wrappings less than this, according to their nature; whilst newsprint is usually made nowadays without any rosin size at all.

Rôle of Alum.—As explained above, the paper maker uses alum to precipitate and fix the size and so to prevent losses through the paper machine wire. The name *alum* is applied by paper makers to aluminium sulphate (chemical formula, $Al_2(SO_4)_3,18H_2O$); it is not to be confused with the true alums, which are more complicated compounds; one of these (potash alum) was, however, formerly used in paper making, but it is relatively expensive. Whether the size or alum should be added first has often been debated. In many cases this does not matter, but if the water is very hard or some other factor causes precipitation of the size before the alum can do it, then it is better to add at least some of the alum first. In any case, the one must be well mixed with the pulp before the other is added.

It is not yet known for certain what compounds are actually responsible for the sizing of the sheet, but there is no doubt that aluminium compounds play an important part, probably by holding the rosin precipitate on the fibre and/or by combining with the rosin precipitate in the form of *aluminium resinates.*

Alum may be added in solution or as a dry powder. The latter method is very convenient; very pure and clean powdered alums are now made, and these can be used dry even in fine papers. If the alum is dissolved acid-resistant piping and storage tanks are required. The amount of alum used for hard sizing is usually a good deal more than is necessary merely to precipitate the size. Only about 0·5 part of alum to 1 part of size is normally required, but up to 3 parts of alum to 1 part of size are frequently used in practice. Most sizes which contain rosin mainly in the free state require much less alum than many rosin soap sizes, but hard water increases alum consumption.

Certain materials, which may be considered as auxiliary sizing agents, are sometimes added to the beater. They include sodium aluminate, sodium silicate, methyl and ethyl celluloses and, most important, starch and the various prepared starches. These usually confer properties other than sizing, such as hardness, rattle and strength.

Sodium aluminate is used to introduce sufficient aluminium into the pulp, while keeping it neutral. It is alkaline in reaction, and so reduces any acidity of the pulp. The copious precipitate it forms also helps to hold the water on the wire of the machine, a valuable point where very thin or free papers are being made; also, frothing on the machine is reduced.

Silicate of soda ("water glass") is a water-white, viscous solution, and is usually added as such to the beater, although it is better to mix it with water first. The addition of alum throws out a voluminous precipitate of aluminium silicate, which holds other sizing and loading agents in the sheet, and is said to improve its rattle, handle and printing properties and to reduce surface fluffing. The resistance of the paper to penetration by printing ink can be increased by closing the formation of the sheet and by the retention of additional fine fibre débris, starch, loading and sizing materials. Since such effects result from the use of sodium silicate, this substance therefore can be considered as a real auxiliary to sizing, although apart from the above effects, it does not itself produce resistance to penetration by ordinary water writing inks. Up to 5 per cent. on the weight of the pulp is used, according to the effect required, but as little as 0·5 per cent. has some effect. Care should be taken that the pulp is finally made acid with alum, or full advantage will not be gained from the silicate. A good way of using silicate is to heat it with starch; the resulting combination is retained very well on the wire, and the maximum value is derived from both materials.

Starch is used in paper for reasons similar to those obtaining in the laundry, namely to give firmness, stiffness and strength, and to aid calender finishing. It also increases the transparency of paper. Various natural starches are used, including those from rice, maize, tapioca and potatoes. These may also be treated chemically or in other ways to produce special properties, such as swelling in cold water or higher solubility. Natural starch may be added to the beater dry, mixed with cold water, or heated in water or in caustic soda solution to swell the granules, so that less is lost through the paper machine wire. The full benefit is not obtained from natural starch unless the paper machine dryers are hot enough to burst the starch granules. The prepared starches are usually added dry; only 2–3 per cent. on the weight of fibre is needed to produce a good effect, whilst up to 10 per cent. of natural starch may be required to obtain the same benefit.

Gelatine.—It is not normally economical to use such a soluble material in the beater, except to obtain special effects, as in some photographic papers. It is then added as a cold solution or thin jelly. *Rubber latex* has been used in specialty papers, particularly to improve folding resistance. The use of *synthetic resins* is referred to on pp. 33 and 176.

Mineral Loadings (Fillers)

Loadings are now added to paper to cheapen production only in the case of definitely low-priced selling lines. They impart such valuable special properties to the sheet that in certain cases they are indispensable. Thus, in general, they produce a better printing surface and absorption of printing ink; higher finish; greater opacity; a close, even appearance; flatness; softness of handle; reduction of expansion and contraction in changing atmospheric conditions; and often an improvement in colour. The strength, bulk and sizing of the paper are, however, reduced.

Loadings are fine white powders, prepared either from natural minerals or by chemical processes. They may be added to the beater dry, but it is much better to mix them with water and to strain the mixture through a wire-cloth screen. In large mills systems of tanks, with continuous agitation and circulation, are used.

The proportion added to the pulp depends, first, on the purpose of the paper and, secondly, on the extent to which the loading used will be retained on the wire of the paper machine; the latter is specially important when large quantities are used, because then quite often less than half the loading added is found in the paper. The proportion retained depends on the kind of loading used and the percentage added; the degree of beating; whether size and alum are used; the substance of the paper; the construction and operation of the paper machine (especially the efficiency of the backwater system, see p. 130); and on other less understood factors, such as the particle size and shape and the electric forces which operate in solutions and suspensions. The amount retained varies from 40 to 80 per cent. of that added to the beater.

Whether the loadings are added before or after the sizing materials depends on circumstances. Thus, size and alum added after the loading tend to hold the latter in the sheet better, but the sizing will be poorer, and vice versa. There has been recently a tendency to add part or all of the loading at the paper machine, either in the chest, in the head box, or over the wire. Such methods have advantages and disadvantages which cannot be discussed here. The kind of loading used depends on its properties, and these are discussed below.

China Clay (Kaolin) is by far the most widely used loading in this country. The best clays are obtained in Cornwall and Devon, from surface pits, usually by washing down with powerful hoses. The resulting milky slurry is run over settling pits, sand traps and screens to remove large particles and impurities, especially grit and mica particles. It is then settled in tanks, when the water is run off and the clay dried in warm air and broken up or powdered.

China clay in a printing paper gives a smooth, receptive surface, which takes printing ink particularly well and accelerates the drying of the ink. The sheet may have a soft, limp handle, but this is an advantage in certain papers such as blottings.

Calcium Sulphate.—There are several varieties of this loading, some being the natural mineral ground to a fine powder (*gypsum, mineral white, terra alba* or *annaline*). Precipitated calcium sulphate is also used under that name, or as *pearl hardening*; it is cleaner and more uniform in quality than is the natural mineral.

This loading is similar to china clay in method of use and effect, but it does not influence the sizing so much, and it is more suitable for use in cheap writings. A disadvantage is that it is slightly soluble in water, and a good deal is thus lost.

Titanium Dioxide is particularly effective for giving opacity and whiteness to the sheet. It is costly, but very little suffices to give a maximum opacifying effect. It is often sold mixed with barium sulphate; this reduces the price, but also to some extent the opacifying effect.

Barium Sulphate or *Barytes* (the precipitated form of which is called *blanc fixe*) is sometimes used to give opacity, low bulk and good surface, but it settles out very quickly, being a very heavy mineral. It is more often used for coating, especially photographic papers.

Magnesium Silicates in several forms (*talc, agalite, french chalk, asbestine*) are frequently used on the Continent and in America, but seldom in this country. Being crystalline or somewhat fibrous in shape the particles are retained better in the sheet than is clay. They give a peculiar smooth feel to the sheet and help to obtain a high finish.

Calcium Carbonate (*precipitated chalk*) is used to some extent, particularly in cigarette papers to give even burning and (in America) for magazine papers. As it is decomposed by acid, it is unsuitable for use in sized papers. It is sometimes made in pulp mills from the causticiser sludge obtained in the soda process (see Chapter IV).

Zinc Sulphide, alone or mixed with barium sulphate (*lithopone*), is used in America and to some extent in this country. It gives a very good opacity, but must be used carefully in the mill because it is liable to darken in colour in contact with copper.

Other Loadings which serve particular purposes in specialty papers include the earth *Kieselguhr*, which consists of the skeletons of tiny water animals and is a very good absorbent and filtering medium; and *Asbestos*, a mineral with a fibrous structure having obvious uses in fireproof papers.

Chemicals such as manganese salts and ferrocyanides are sometimes added to the beater in making safety cheque papers. Attempts to bleach out the ink on the cheque result in brown stains.

Colouring

Probably the most interesting yet difficult of the paper maker's tasks is the dyeing of the paper to a correct colour. It is interesting because of the beautiful and varied results obtainable with modern colouring matters; difficult because a knowledge of dye and pigment properties and a fine judgment are required to obtain accurate shades. The paper maker has also to correct the shade of most white papers by the addition of small quantities of blue, pink or violet colours, which counteract the natural yellowish tint of bleached fibre, just as "blue" is used in the laundry to make white articles appear whiter.

When a new shade has to be matched, it is usual for the colour combination to be worked out in the laboratory, where hand sheets are made and compared with the pattern. The selection of the colouring matters to be used depends on the shade desired, on the degree of fastness to light and other factors which cause colour changes, and on the price and purpose of the paper.

In the space here available, only the main classes of colouring matters can be discussed. They fall into two main divisions, namely, the insoluble mineral *pigments* and water-soluble *dyes* (usually *aniline dyes* made from *coal-tar products*). An intermediate class derived from the coal-tar colours is the insoluble organic pigments. There are also a few colours, little used nowadays, which are extracted from natural products such as plants. The Table (p. 112) gives a few typical colours in each class, with some of the papers in which they are used.

The Coal-Tar (or Aniline) Dyes are a very large class covering every possible shade, and they are widely used. Their chemistry is complicated and difficult, but they can be divided roughly into classes according to their properties and dyeing procedures. The three most important of these classes are the *basic*, *acid* and *direct*

NATURAL DYESTUFFS

Colouring Matter	*Use*	*Mordant*
Logwood	Black papers.	Iron salts.
Vandyck brown	Brown wrappings.	Alum.
Cochineal	Tinting white papers.	Size and alum.
Fustic	Cheap yellow papers.	—

PIGMENTS (Water-Insoluble)

Colouring Matter	*Use*	*Mordant*
Inorganic.		
Ultramarine	Good azure and blue ledgers and writings, and for tinting whites.	Size and Alum.
Smalts	Best writings and ledgers.	
Prussian blue	Fast blue tints (for covers).	
Ochres	Dull red, yellow and buff papers.	
Siennas	Brown papers.	
Umbers	Brown papers.	
Lead chromates	Bright yellow and orange papers.	
Carbon black	Black and grey papers, and for dulling brighter shades.	
Organic (Coal-tar or aniline).		
Caledon colours	High-class writings.	
Monolite colours	High-class writings.	
Monastral blue	Good quality blue papers, replaces Prussian blue.	

SYNTHETIC COAL-TAR DYES (Water-soluble)

Colouring Matter	*Use*	*Mordant*
Acid.		
Quinoline yellow	Sized papers, writings, typewritings and printings.	Size and alum.
Croceine scarlet		
Soluble blue		
Basic.		
Auramine	Cheaper coloured papers of all kind.	Size and alum. Tannic acid.
Methyl violet		
Victoria blue		
Direct.		
Chlorazol yellow	Unsized, mottled and better-class coloured papers.	Salt, copper sulphate, and heat.
Chlorazol blues		
Chlorazol blacks		

dyes. These water-soluble dyes vary in properties from good fastness with moderate tinctorial power, brightness and cost for the direct colours, to extremely poor fastness, but high tinctorial power and brightness (and consequently low cost) for most of the basic group. The basic dyes are used largely for the less pure furnishes, such as mechanical and unbleached chemical wood pulps. The direct dyes are less suitable for such furnishes (quite apart from their greater cost), but will dye the purer forms of cellulose without a mordant (see below).

Inorganic Pigments are almost all very fast to light, but with few exceptions (as ultramarine and chrome yellow) they are dull in shade. The synthetic coal-tar pigments are also usually fast, but are often weak in colouring power and, in consequence, expensive to use.

Use of Dyes in the Mill.—It is possible with most pigments and many of the soluble dyes to add the colour in the dry, powdered form to the beater. However, it is much better practice first to dissolve the dyes in (or mix pigments with) water, and to strain through a wire cloth before adding, because of the danger of dirt and dye specks.

Great care must be taken when dissolving dyes, as the exact procedure varies from one to another. Dye solutions should be used cold and diluted, and added gradually so as to avoid overdyeing some of the fibre and so producing a mottled final effect.

An interesting application of dyeing is the production of mottled (*silurian*) effects by adding to the main furnish about 1 per cent. of a fibre which has previously been dyed deeply with a colour which will not bleed out into the rest of the furnish. The mottling fibre is usually dyed hot, with a direct dye, with the addition of salt and/or copper sulphate to fix the dye.

Mordants.—Most of the direct dyes fix themselves on the fibre without assistance, and in consequence are used for unsized papers such as blottings; the others (and especially the acid dyes) require the addition of chemicals to minimise loss in the backwater of the paper machine. The rosin size and alum normally present are usually quite efficient for this purpose; but tannic acid (for basic dyes), copper sulphate, sodium sulphate and common salt are sometimes needed.

If a mixture of dyes is to be used to produce a desired shade, the constituents may often be chosen so that they fix one another; if they are added separately this is a valuable device for producing fast deep shades. If freshly prepared pulp is being used, it may contain unexhausted bleaching liquor, which will, of course, partly bleach certain dyes. Also, if allowed to remain in the pulp, such residues will cause the resulting paper to deteriorate in strength. An *antichlor* (see p. 89) is therefore added to the beater to destroy the bleach; a few pounds usually suffice to treat a ton of pulp.

Final Pulp Cleaning

Although in the process of pulp manufacture all fibrous paper-making materials undergo extensive cleaning and washing (see Chapter VI), the disintegrating action of beating releases more dirt; also some additional foreign matter is inevitably derived from the various materials added to the beater, as well as, possibly, from the pipe-lines and other plant. Before the finished beaten pulp is ready for the paper machine, it is therefore again thoroughly cleaned. In

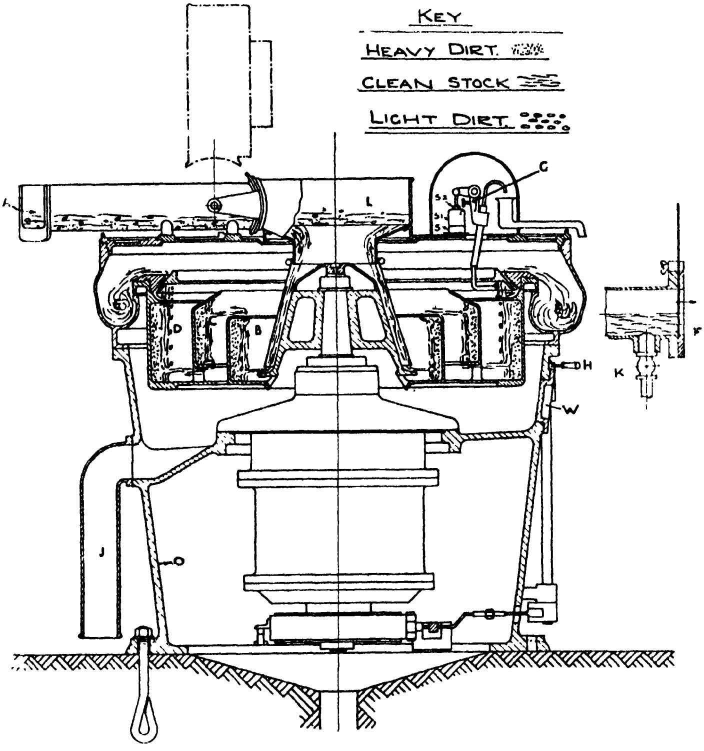

Fig. 46.—Centrifugal Action Pulp Cleaner.

A. Untreated pulp entry. B, C, D. Dirt collecting baskets. E. Purified pulp. F. Pulp outlet. G. Light impurities extractor. H. Emergency brake. J, K. Washing out valves. L. Central inlet distributor. O. Outer casing.

general principles the methods used are similar to those described in Chapter VI, to which reference should be made.

Few mills are exactly alike, but the general principles of such cleaning follow two main lines, namely: (1) removal of dirt that is lighter or heavier than fibre by flotation or settling, respectively, processes which are now carried out very conveniently and rapidly by centrifugal separators; and (2) separation of fibre lumps and stringy material by means of slotted strainers.

For efficient cleaning dilute stuff is necessary. Cleaning therefore usually takes place just after the stuff has been pumped from the machine chest, regulated in flow and diluted to the correct consistency for making into paper. The cleaned pulp is then ready to be projected on to the wire of the paper machine.

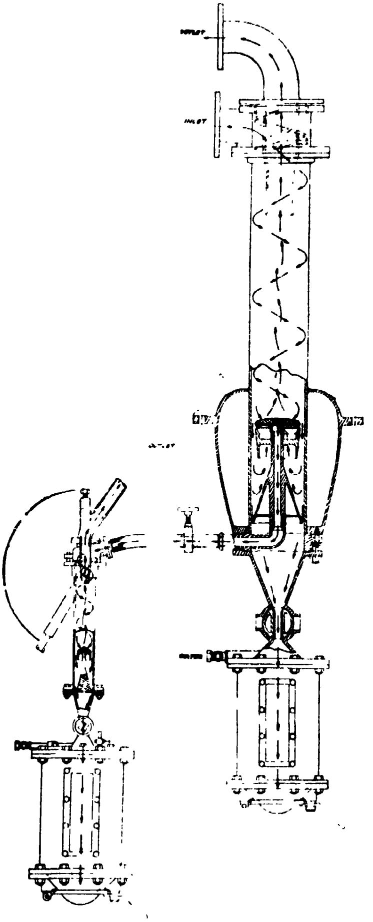

Fig. 47.—Vortex Action Pulp Cleaner.

Arrows show the direction of flow of pulp, some of which is treated further in the smaller auxiliary cleaner at the left. The heavy dirt collects in the lower vessels.

The Sand Trap is the simplest device for the removal of dirt. It consists of a long, narrow wooden trough, in the bottom of which are usually fitted cross slats (*riffles*) over which the pulp flows slowly, and behind which the heavy dirt is trapped. Floating impurities (*e.g.* rubber) may be skimmed off the surface, and magnets may be placed in the bottom to attract iron particles (see also p. 52). Sand traps are cheap to construct and require no power, but they are cumbersome and remove much good fibre.

Centrifugal Cleaners.—Modern machines are frequently fitted with these as well as, or in place of, the sand trap. In one type a rapidly spinning central rotor produces the centrifugal action. The dilute stream of pulp is fed into the centre of the rotor, and is flung outwards against the walls, where the heavy dirt is separated by its higher momentum and is trapped under ledges. Light dirt can be skimmed from the surface of the rotating stuff. Another type consists of a vertical tube, into the top of which a jet of dilute pulp is pumped at a tangent to the sides; the vortex action of the spinning pulp stream passing down the tube throws out the dirt, which is removed continuously from the bottom. The path of the stuff through these cleaners can best be followed in Figs. 46 and 47, respectively.

Strainers.—There are many variations in the design of these machines, but they may be divided into two main types, namely, the flat stationary and cylindrical rotary types (see Chapter VI). All are alike in that they are fitted with metal plates in which are cut numerous fine slits; these vary in width from about 0·007 to 0·017 inch, according to the type of paper being made. The fibres (which are long in relation to their width) pass through such slits, while the irregularly shaped dirt and lumps are held back. An agitating device, such as a vibrating diaphragm, keeps the pulp on the move and helps it through the slits.

Flat strainers (see p. 90) in their simplest form consist of a metal tray in the bottom of which are the horizontal plates. The stuff may flow either up or down through the plates, but the latter is usual. The dirt and lumps are scraped off the surface of the plates continuously, and the clean pulp flows away from under the tray.

Cylindrical rotary strainers (see p. 82) have their slotted plates in the form of a hollow, open-ended cylinder, which rotates in a vat. The end edges of the cylinder may be sealed by rubber bands or water chambers, and the stuff either flows in through the face and out through the ends, or vice versa. The cylinder face is continuously cleaned by water sprays.

In order to prevent loss of good fibre, the matter rejected from a strainer may be diluted and passed through a small auxiliary flat strainer; any good fibre recovered is returned to the main stream of stuff flowing to the paper machine.

CHAPTER IX

THE PAPER MAKING OPERATION—I

HAND-MADE PAPER

It is evident from Chapter I that the historical importance of hand-made paper cannot be over-emphasised. Since the beginning of the nineteenth century, however, the industry in this country has decreased in volume to the present annual production of about 350–400 tons. Nevertheless there is no indication of its disappearance, as there is always a demand for the highest qualities of paper, a demand largely satisfied by the hand-made product. Some buy hand-made paper merely because they fancy it; but others are willing to pay a high price for it because of its high quality, and in particular its fine texture, strength and permanence. Thus, a graphic artist or draughtsman may expend so much time and effort on a single sheet that only the best will do.

The preparation of the pulp follows the same lines as those described in Chapter IV, except that throughout special care is taken to produce a clean and pure cellulose pulp. The raw material is always rags (p. 52), usually cotton, linen or hemp, and may be new or old so long as it has not suffered chemical damage. The grade used depends on the purpose for which the paper is intended. Thus soft rag, such as old muslin curtains, yields a soft paper for filters; a hard rag, such as cuttings from yacht sails, makes a hard sheet such as a loan; drawing paper is made from appropriate mixtures of old cotton and linen rags.

Rags for fine papers are always regraded and cut by hand as described in Chapter IV. They are then dusted in a revolving duster and bagged ready for boiling, which is carried out in stationary or revolving boilers or in open kiers. Frequently it consists of mild treatment with a solution of soda ash, though there is little risk of damage when the more active caustic soda is used provided that contact with air is avoided during boiling. After boiling the material is washed in the boiler with warm water or emptied out and washed subsequently.

Breaking and washing are done simultaneously in a potcher or breaker (p. 54). In the early stages girls pick out by hand any coloured pieces or other foreign matter floating on the surface. As the dirt is loosened it is washed out, and at the same time the fibres are completely separated, care being taken to avoid cutting them unduly.

Bleaching follows, usually in the same potcher. Care must be taken to avoid any chemical attack of the fibre, not merely because the strength of the paper will be reduced but also because its permanence will be impaired. Consequently, the hypochlorite bleaching solution used should have a high alkalinity, and excess should be avoided. The bleached pulp must be thoroughly washed.

Beating is dealt with in Chapter VII; very careful treatment is important. Additions to the fibre furnish include soap or starch and possibly fast-to-light colouring matters; smalts is frequently used for tinting. The beaten pulp is emptied into a stuff chest, usually lead-lined for cleanliness. From the chest an excess of the stuff is pumped to the *head box*, the surplus flowing back to the chest. In this way a constant head of regular stuff can be maintained. This is diluted in the mixing box with *backwater* drawn from near the top of the vat; the mixture passes over *sand traps* and through a *strainer* (Chapter VI) to the vat.

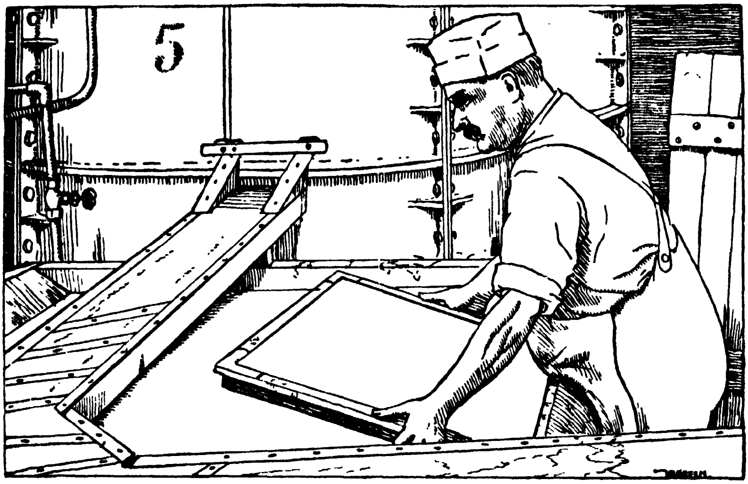

Fig. 48.—Vatman at Work.

The *vat* is usually a rectangular tank 6–8 feet long and about 4 feet wide and 3 feet deep, fitted with a *hog* (or agitator) and a steam pipe for heating the contents. The latter is partly for the comfort of the vatman, but principally to enable wet beaten pulp to drain more readily. Along the length of the vat is a shelf or bridge, with a curved bracket at one end known as the *ass* (Fr. "arche"); it is shown in Fig. 49.

Making the Sheet.—The *moulds* are made in pairs (Figs. 48, 49). The frame is straight-grained mahogany, or similar wood that resists alternate wetting and drying. V-shaped wooden bars across the frame with their narrow edges level with the top of the mould support wires at right angles to them, and form a foundation for the straight wires or woven wire fabric (for laid or wove paper, respectively) which forms the actual draining sieve. The whole is sewn down to the cross-bars so as to maintain a perfectly flat surface. If a watermarked paper is required, the device in wire is sewn or soldered to the surface of the mould. All ends of wire which might collect fibres are covered with thin copper strip, and the whole is brass-bound and stiffened so as to produce a rigid mould. Each pair of moulds has a *deckle*, a wooden frame about 1¼ inch wide and ½ inch deep, which fits easily over the mould and forms a frame for the sieve.

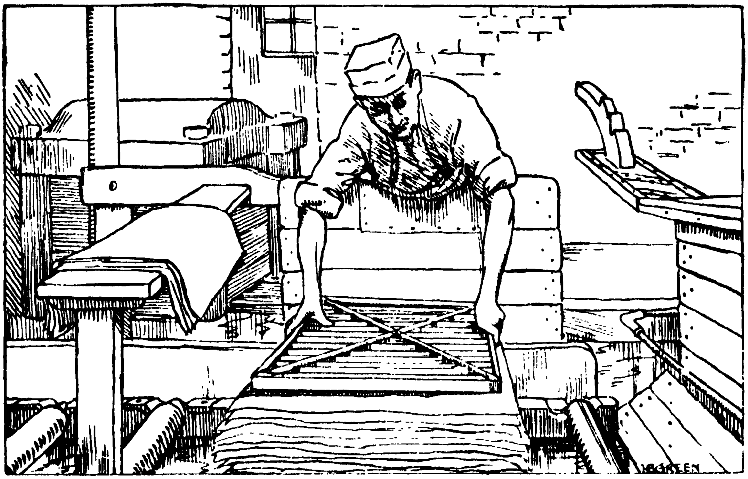

Fig. 49.—Coucher at Work.

The vatman (Fig. 48) takes the mould with the deckle on it and, holding it vertically with the wire side towards him, dips it into the suspension of pulp, bringing the lower edge towards him until the mould is horizontal and has scooped up rather more than sufficient pulp to form the sheet. As the mould is raised and the water drains away, it is tilted slightly, and the vatman shakes it to and fro, from left to right, so that a " wave " runs across it from the back (nearest to the vatman) to the front, thus carrying off the excess of stuff. He then shakes it horizontally from back to front, and as there is just sufficient water present to enable the fibres to move, they tend to deposit uniformly and in all directions on the mould. A closer, more regular sheet thus results. The deckle is removed, and the mould with its layer of pulp placed against the ass to drain. The vatman then places the deckle on his second mould, and proceeds to make the next sheet.

The joint between the deckle and the mould is not sufficiently close to give a clearly defined edge to the sheet, and the few fibres that penetrate the joint form the irregular *deckle edge* characteristic of hand-made paper. Normally a mould makes one sheet of paper; if, however, the sheets are smaller than about 20 by 25 inches, it is customary to divide the surface of the mould so as to make eventually two or four separate sheets in one operation, by tearing the finished sheets apart at the thin places formed by the dividing lines. Alternatively, a wooden cross-bar fitted on to the deckle leaves two separate sheets when the deckle is lifted off.

The whole operation requires much skill in order to make a uniform paper of the desired texture and of the correct weight. A vatman may have been making one order with pulp beaten in one way for a considerable period, and he then has to change to another order of a different weight and type of pulp. The high level of his art will thus be appreciated.

The *coucher* (Fr. "coucher," to lay down) has already placed one of a number of pieces of woollen felt (rather larger than the sheets being made, and wetted out in water and pressed) on a movable wooden platform. On it he now couches the sheet from the mould by inverting the mould on to the felt, one long edge first, pressing, and removing the mould, again from one edge first (Fig. 49). In this way the sheet is transferred from the mould to the felt. The mould is returned to the vatman, and the sheet of wet pulp is covered with a second felt in readiness for the next sheet of pulp. In this way is built up a *post* (origin uncertain), about 18 inches high, of alternate felts and sheets of pulp. This is covered with a *pilcher* (Fr. "pelisse," furry cape), a wad of felts sewn together, and subjected to a pressure of about 2 tons per square inch on a 10-inch ram in a hydraulic press. Sufficient water is thus removed to enable the sheets to be handled.

After pressing, the *layer* removes the post from the press and separates the felts from the sheets, the felts going back to the coucher for re-use and the sheets being laid on one another to form a *pack* about 4 inches thick. Unless a rough finish (p. 122) is required the pack is placed between thick zinc plates and again pressed, together with several other packs, for several hours under a pressure of about half a ton. The first pressing leaves marks from the threads in the felts on the sheet; the second reduces these irregularities, producing a smoother sheet. The sheets are then *parted* (separated), and sometimes a third pressing is applied if a higher finish is desired.

Drying and Sizing.—For many years it was customary to dry the sheets by hanging them over ropes (made of cowhair to reduce marking at the fold) in wads of four to ten, depending on their thickness. The ropes were stretched horizontally across *lofts*, in which the air was warmed so that drying was complete in 3–4 days. Nowadays the sheets are usually dried flat, being laid on jute scrim stretched over horizontal wooden frames which can be raised or lowered in the loft (Fig. 50). This method takes more space and time, but it avoids creasing the middle of the sheet.

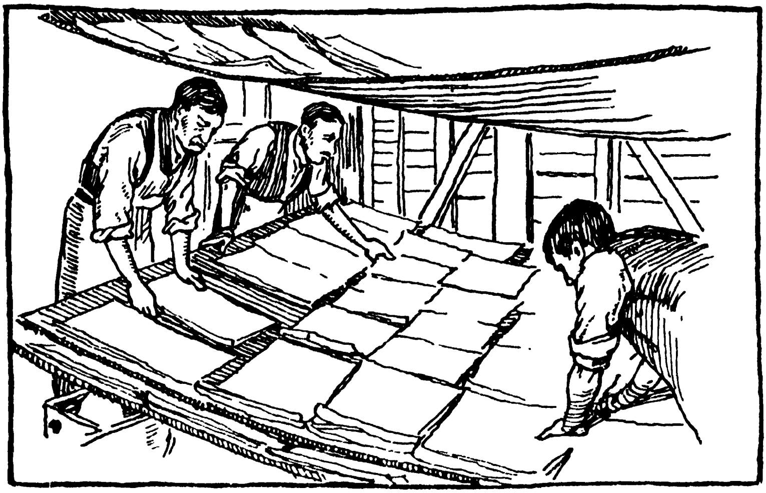

Fig. 50.—Loft-Drying Hand-Made Paper.

After drying the paper is matured in stacks in a cool place. The stacks are turned and restacked from time to time, so that air permeates the paper and cockles are gradually eliminated. When reasonably flat the unsized paper (*waterleaf*) is ready for sizing.

Tub-sizing is described in Chapter XI. With hand-made paper the size is always a solution of gelatine, sometimes containing soap, together with alum and perhaps a preservative. Formerly the sheets were hand-dipped in the size and squeezed in a pack. Nowadays the sheets, held between two continuous felts, are passed slowly through a bath of the size and then through squeezing rolls. After sizing they are piled into packs and allowed to stand overnight, drying at the edges being prevented by covering them with a dry felt. The sheets are then parted and loft-dried. For extra hard sizing a second treatment is given. Much skill is required in sizing, not only to suit the kind of paper but according to the weather. For instance, a first-class drawing paper is preferably sized during the winter months rather than in the summer; again, very different strengths of size are required for, say, printings and loans.

Finishing.—Hand-made paper is sold in three different degrees of finish, viz. *Rough, Not* (not glazed), and *Glazed* or *Hot-pressed* (*H/P.*)—see p. 29. To obtain the rough surface the pressing in packs is omitted, the sheets being dried after the first pressing. A glazed paper is plate-glazed (p. 159), being pressed twice, four or more times, between metal plates. The not surface is intermediate in smoothness between the other two.

The finished paper is again stacked for some months in piles, which are opened up and restacked from time to time. This treatment gradually removes the cockles. Finally, women sort the sheets (in the *salle*) and remove slight blemishes such as wool fibres or dirt on the surface (*picking*). The paper is sorted into *Good* or *Seconds*. The seconds is reclassified as *Retree* (Fr. "retrié," re-sorted) and *Outsides*; badly torn or soiled sheets (*Bad Broken*) are repulped.

THE PAPER MACHINE—WET END

Introduction

The first Fourdrinier machine of 1803 (see Chapter I), though small, slow and simple compared with a modern machine, was based on similar principles. To-day it consists essentially of an endless woven-wire gauze stretched over rollers; this corresponds with the foundation of the hand mould (p. 119). The portion of the wire on which the sheet is formed travels approximately horizontally at a steady speed from the breast roll to the couch. The suspension of pulp (the *stuff* or *stock*) flows on to it in a regular stream, at such a rate that it has about the same velocity as that of the wire. A strip of fabric trailing on the wire makes a joint and prevents leakage of stock off the wire. Sides to the wire are provided by deckle straps or a similar device.

The flow across the machine is controlled by adjustable strips of metal on edge and dipping into the stream. The frame supporting the wire is hinged so that it can be shaken laterally. The wire is supported on rollers, and contact between them and the wire assists the draining away of the water. More water is removed by passage of the wire over open boxes connected to a vacuum pump. At the couch the sheet of pulp is sufficiently coherent to withstand transfer to a felt, on which it is pressed.

In Donkin's machine the web at this stage was reeled up wet, to be cut into sheets subsequently and dried like hand-made paper. In 1821 Crompton patented the use of steam-heated drying cylinders, and so produced dry paper in one continuous operation.

The various parts of the machine will now be dealt with separately in greater detail. Reference should be made throughout to Fig. 51, which is an isometric drawing of a typical complete paper machine, showing all the essential parts.

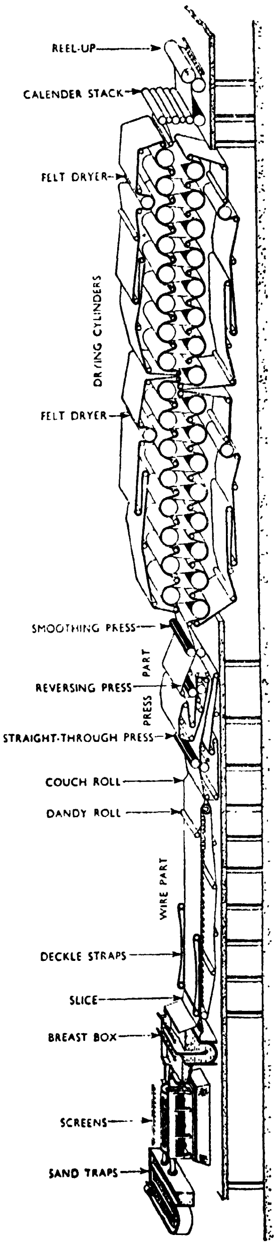

Fig. 51.—Typical Fourdrinier Paper Machine.

Final Preparation of the Stock.—The stock in the machine chest is, except for some further cleaning, ready to be made into paper. In some mills this chest is used as a final mixing vat for the constituents of the furnish; in others it is just a reservoir of prepared stuff from which the machine is fed. The chest is usually a large, vertical, cylindrical concrete vat of suitable capacity, and it is invariably fitted with an agitator such as a revolving gate, paddle or circulating pump.

A plunger or centrifugal pump draws the stuff from the bottom of the chest and lifts it to a ***head box*** placed well above the level of the wire of the paper machine. This stuff pump must be large enough to deliver more stuff than is required to feed the machine; the excess overflows from the head box back into the chest. The head box, which may be several cubic feet in capacity, is a constant-level box by reason of this overflow. It has an outlet at the bottom (the ***stuff tap***), at which the amount of stuff flowing to the machine is controlled.

Somewhere between the beaters

and the head box, and usually between the machine chest and the box, should be a *consistency stuff-regulator* to control the concentration of the stuff in the head box by adding water as required. Such regulators usually depend for their action on the viscosity or ease of flow of the stuff, the effect of an increase in viscosity (due to an increase in consistency) being to open a water valve, and vice versa. Some use a float to control the water valve; others depend on the resistance to the flow of stuff down a pipe. None is entirely satisfactory.

The backwater coming from the trays under the wire or from the machine pits is mixed with the thick stuff flowing out of the head box, usually in a mixing box, and the dilute stuff (which may contain about 1 per cent. or less of fibre) flows to the cleaning devices described on p. 114 and below.

At this stage the most satisfactory type of strainer, from every point of view, is the cylindrical inward-flow type. It runs for many hours without attention, and keeps back knots and lumps and, in the case of rag papers, rubber. A recent method of dealing with the stuff bled from the bottom of the main strainer is to pass it through a very small, high-speed refiner. This cuts up all knots and lumps, the whole of the resulting stuff being put straight back into the chest or mixing box, whence it passes to the paper machine. Thus lumps of stuff and strings, especially in rag papers, are withheld when an auxiliary strainer is used; whereas the refiner resolves them again into fibres, which are passed back into the stock, thus minimising losses. This method, of course, does not get rid of any dirt or lumps, but presupposes that the stock is properly cleaned before it reaches the main strainer. From the main strainer the stuff passes to the breast box.

The Wire Part (see Figs. 51 and 53)

The *breast box* (Fig. 52) is a levelling tank used to even out the flow of the stuff before it reaches the wire, and is constructed so as to keep the fibres and water thoroughly mixed, and to deliver them to the slice in a regular and level stream. Breast boxes vary considerably in design, according to the type of stock and, especially, paper-machine speed. For instance, with rag stock the simpler the construction of the breast box the better. It should be made of copper and monel metal, with no rough parts, which would tend to cause knots and lumps to form. However, with wood pulp furnishes (such as for newsprint) the breast box may be more elaborate, and may have devices (such as baffles and perforated plates), for thoroughly mixing the stock, without the same risk of knot formation as with rag stock. The head of the stock in the breast box must be such that the stock will pass on to the wire with an even flow right across, with the fibres, water and loading equally distributed, and with a velocity approximately equal to that of the wire.

The best type of *slice* is the projection slice, since the secret of a good formation in the sheet is to get the stuff by the shortest route from the breast box on to the wire. The Voith-type projection slice is that most commonly in use, and the newer designs seem to have very few advantages over the originals. This slice consists of a rigid, smooth, level bottom plate forming a continuation of the breast box; the lip of this plate ends approximately over the centre of the breast roll (see p. 126), and so delivers the stock on to the wire absolutely level and with a velocity which obviates the necessity for an apron (p. 126). The chief feature of the projection slice is, however, the flexible upper lip, which can be opened as required by a number of separate hand-wheels. These can vary the depth of the opening at any point across the machine, thus enabling the machine man to make adjustments for any faults in the flow, due to streaming or other irregularities in the breast box. Immediately behind the projection slice itself is a perforated metal roller revolving slowly in the

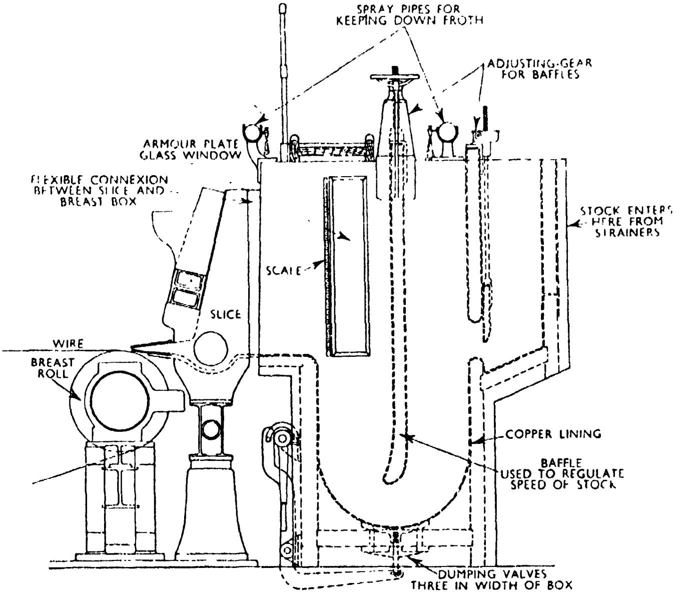
SPRAY PIPES FOR KEEPING DOWN FROTH
ADJUSTING-GEAR FOR BAFFLES
ARMOUR PLATE GLASS WINDOW
FLEXIBLE CONNEXION BETWEEN SLICE AND BREAST BOX
STOCK ENTERS HERE FROM STRAINERS
SCALE
SLICE
WIRE
BREAST ROLL
COPPER LINING
BAFFLE USED TO REGULATE SPEED OF STOCK
DUMPING VALVES THREE IN WIDTH OF BOX

Fig. 52.—Breast Box, with Projection Slice.

stock (*monkey roll*). This prevents the stuff from settling out before it passes on to the wire.

Slower machines still use the older arrangement of the *apron* with one, two or three slices. The apron is simply a short length of fabric or rubber which bridges the gap between the breast box and the wire. Such slices consist of a metal strip placed vertically above the stream of pulp flowing on to the wire, and adjustable in height so as to control the velocity of the stock and the amounts discharged on to the wire across its width.

Before the stuff leaves the breast box it should preferably be heated by steam to make it part with its water more readily on the wire, and a device for maintaining a constant temperature is desirable if regularity of make is to be maintained. The most suitable temperature for the paper must be determined by the paper maker.

The stock passes from the lip of the slice on to the endless phosphor-bronze wire cloth, which carries it from the breast box to the couch. The mesh varies according to the paper being made; for instance, for heavy and coarse papers the mesh may be as low as 50 (that is, 50 wires to the inch in the weave); for the finest tissues it may have a triple warp (with a mesh of 65 weft and 195 warp, which is equal to about 90 mesh in a plain weave). The wire is woven in long lengths and cut by the makers into pieces; when the ends are joined together, each has a length suitable for a particular *wet end* of a paper machine. The ends of the wire are joined by welding each warp wire to its opposite number at the other end of the wire cloth. This makes a joint which does not mark the paper, and is preferable to a soldered seam and much better than a sewn seam.

The wire is supported by causing it to run round first the *breast roll,* then sometimes over a *forming table* and then over revolving rolls called *tube* or *table rolls,* which revolve preferably in antifriction bearings. The tube rolls vary in diameter from 2–12 inches, but generally speaking they should be as large and smooth as possible; any ridge or roughness may damage the wire. The tubes are usually made of brass, but this is too heavy and puts an unnecessary strain on the wire cloth. A light aluminium alloy which does not corrode in presence of water, or aluminium covered with rubber or a plastic, is preferable, so long as the rolls can be properly ground and balanced. The number of tube rolls depends on their diameter and on the length of the wet end, as one of their functions is to assist water removal from under the wire.

After it passes over the last of the tube rolls, the wire passes over the *suction* or *vacuum boxes,* which also support it. These also extract water from the web of paper stock, since they are connected to a vacuum pump which draws water and air out of them, and thus enables them to take more water and air from the wet web of stock. The water is discharged into a tank, and the air passes through the pump.

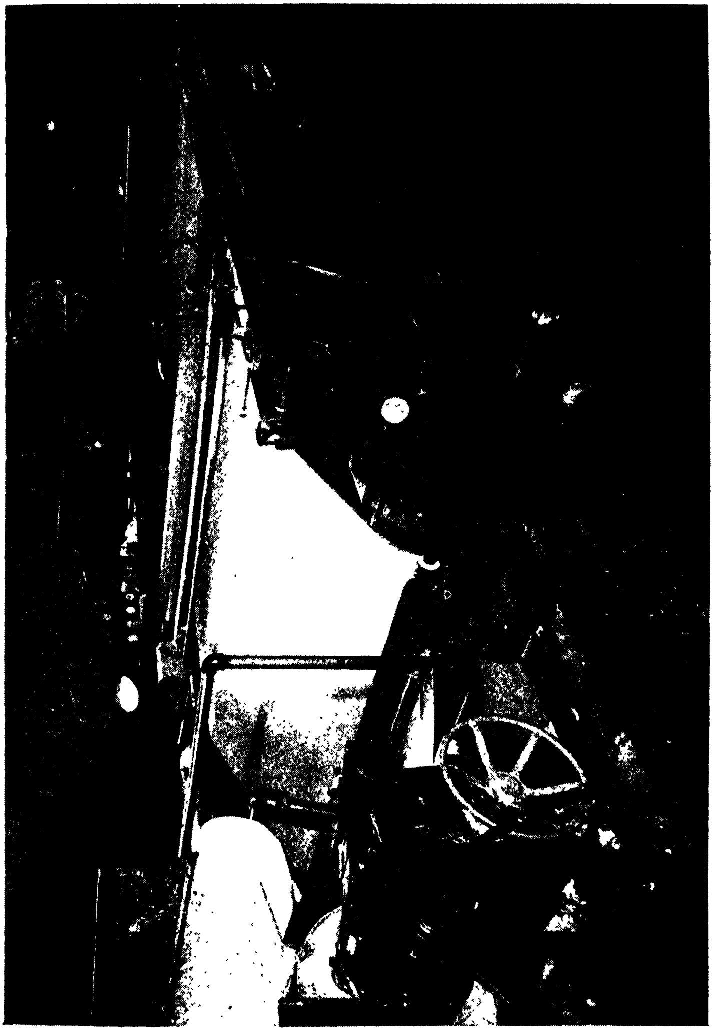

Fig. 53.—Typical Fourdrinier Wet End (with Suction Couch)

The number of vacuum boxes varies from two to ten according to the type of paper and the speed of the machine. With a few boxes it is usually necessary to employ a fairly high vacuum, but with a large number a much lower and better graduated vacuum may be used; this causes less wear on the underside of the wire and gives the machine man better control over the character of the sheet, especially if a watermarking roll (see below) is used. For the same reason, each box should have independent control.

The *dandy* (or watermarking) *roll* is supported so that it touches the wire lightly between the suction boxes, its exact position depending on the degree of water removal necessary for the type of paper being made, and the kind of watermark. In its simplest (or *wove*) form (Fig. 54) it is a metal roll covered with a plain bronze or monel-metal mesh wire cloth (50- to 90-mesh), and its purpose is to close up the sheet and give a clear *look-through*. If a watermark has to be put into the sheet, then the design of the watermark is soldered or sewn in copper wire on to the woven wire cloth. This presses into the stuff, making the paper slightly thinner and more compact under the wires of the design, so that the design is reproduced in the paper. Immediately after the wet web leaves the dandy, the remaining suction boxes draw more water from it, and definitely fix the watermark so that it cannot be obliterated by any subsequent pressure.

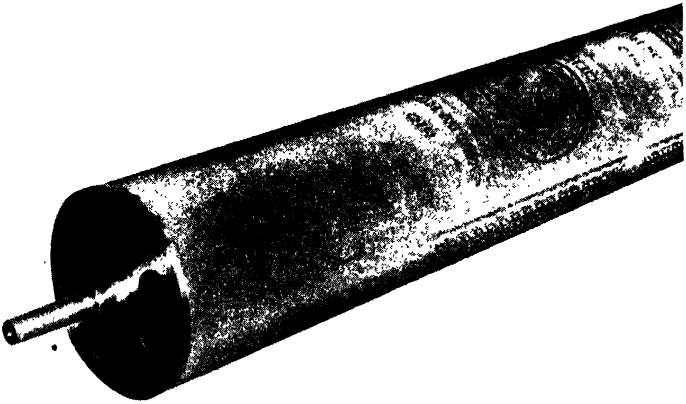

Fig. 54.—Wove Dandy Roll, with Watermark.

Another type of dandy roll gives a *laid* impression to the paper (Fig. 55); it has a series of wires running across the machine direction (*lay wires*) and a series of other lines, made by protruding plates or twisted wire (*chain lines*), which make a mark down the sheet in the direction in which the machine is running. In the laid dandy the chain line wires or plates serve to hold the lay wires in position. In a *spiral dandy,* the lay wires run round the dandy and there are seldom chain lines; the laid mark is thus made across the web.

The dandy roll may be a simple cylinder with its end journals running in bearings, or it may be hollow, with flanges at each end, running on rollers. It is important that there should be exact control of the pressure of the dandy on the stuff. Most dandies are driven by contact with the moving stuff on the wire, but some are now driven slightly faster than the wire; this gives better sheet formation (due to the absence of drag) and a clearer watermark. There is also less distance between the watermarks for a given diameter of dandy.

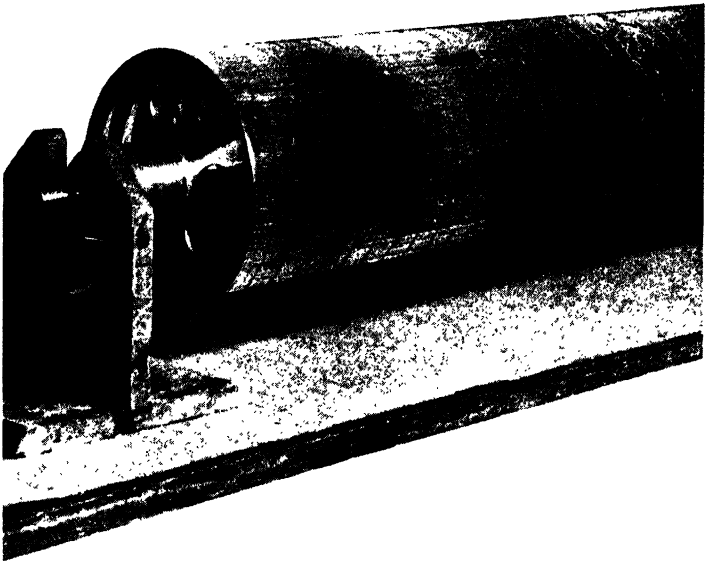

Fig. 55.—Laid Dandy Roll, with Watermark.

After the wire leaves the last suction box it passes over the *guide roll,* which automatically prevents the wire from travelling askew. On some machines the guide roll is placed underneath, on the return journey of the wire, but this as a rule is less satisfactory. The guide roll is operated by the edges of the wire pressing against vertical, spade-shaped pieces of metal, which actuate a screw and automatically alter the position of the guide roll in relation to the wire.

A *shake* motion is usually applied at the breast roll end of the wire frame. It causes the breast roll and wire table to oscillate from side to side, at a high speed, thus assisting to felt the fibres together. Some wire parts are divided, and are shaken in two halves, while on others only the breast roll shakes; the whole operation is extremely important, and has a great bearing on the appearance of the sheet and the removal of water. It is necessary also to prevent the stock from flowing over the sides of the wire by the use of *deckle straps*. These are adjustable endless rubber bands of square cross-section which travel with the wire, resting on its surface at each edge; their weight is sufficient to make a joint which is almost watertight. An alternative to the deckle strap is the Wentz deckle, which is a piece of rubber fixed to a brass plate and extending 2 to 6 feet down the wire.

The water which drains through the wire into the trays below is called *backwater* or *whitewater* (although it may be coloured if dyes are used). This water is valuable, and every drop of it must be reclaimed for re-use. It usually runs from the trays into a sump, from which it is pumped up into a tank to feed the mixing box of the machine (see p. 124). Any excess is used to fill or empty beaters and to dilute the beater stock to a condition suitable for agitation in the chests. The importance of using the whole of this water arises from the fact that it contains fibres which have passed through the machine wire, loading materials, alum, size, dyestuffs, and it may be hot; and every care should be taken to see that none of it is wasted. A recovery plant must be installed in mills making short runs of many different papers or where there is a surplus of backwater, to concentrate the fibres and loading for subsequent return to the beaters. Shower pipes are necessary under the wire on its return journey to the breast roll, to clean the seam and mesh free of fibres and loadings; otherwise the wire will gradually clog up and refuse to drain properly, and it will be impossible to make an even sheet. Showers to remove lumps of pulp are also desirable on the breast and first return rolls.

The Couch and Press Section

After the wire guide roll (p. 129) comes the *couch*, which nowadays is usually of the vacuum type. It drives the whole of the wire, and with it the breast-, return-, and tube-rolls. There are several satisfactory types of suction couch, and they remove from the web of paper as much water as can be taken out by suction.

The Suction Couch Roll (Fig. 56) consists of two main parts, namely a perforated bronze or stainless steel shell with an internal box fitting closely to the shell, in order that a vacuum of 10–12 inches may be maintained by the powerful pump connected to it. The shell has plain or countersunk circular perforations, the diameters and spacings of which vary according to the conditions. The thickness of the shell is also important, as it is much easier to remove water from a thin one; it should therefore be no thicker than is required to give adequate strength without deflection. Some suction rolls are made so that the box is a sliding fit into the perforated bronze shell, whilst in others the suction box is pressed against the inside of the shell by springs. There are also internal deckles in the suction box, which may be screwed in or out according to the width of the web passing over it.

Some suction rolls can be cantilevered from the back side, and this is an advantage when changing wires, as only the front bearing has to be removed, when the wire can be slipped into place and the roll lowered back on to the replaced bracket. The idea that suction couches produce two-sidedness in coloured papers seems to be much exaggerated, as the vacuum used is not likely to have a much more serious effect than the machine wire suction boxes themselves. It is important that the web passing over the suction roll should pass beyond the area of the suction box before being taken off on to the wet felt; otherwise there is likely to be *shadow-marking* (a shadowy reproduction of the perforations of the couch seen on the surface or in the look-through of the sheet).

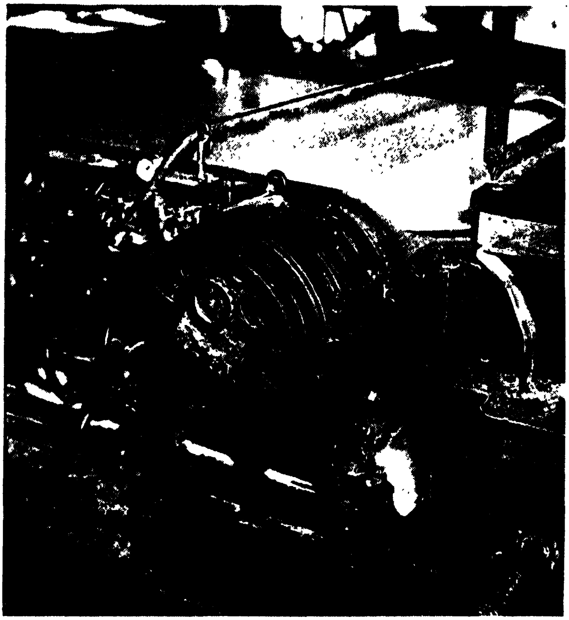

Fig. 56.—Suction Couch.

A Press Couch is used on many older machines in place of a suction couch. It consists of a plain brass roll (the bottom couch roll) which drives the wire; and on top, set several inches off-centre towards the breast roll, is the top couch roll which is covered with a woollen felt jacket. This roll, in turn, has a guard board or small press roll on it, to press the water out of the felt jacket and cause it to run off at the edges; this partly dries the jacket before it comes into contact with the paper. The effect of this couch is to consolidate and dry the paper web sufficiently for it to be transferred from the wire to the wet felt. In the case of the press couch this operation is done by hand, which is a skilled operation. With the suction couch, however, compressed air is often used to blow the web off the wire on to the wet felt.

The moisture still left in the web of paper when it leaves the wire and enters the press part varies according to the nature of the paper, the stock from which it is made, and the substance of the paper. It generally averages about 84 per cent.

A *wet felt* carries the web of paper through the *first press*. It is a shrunk, woven woollen fabric which usually has a raised surface (*nap*) on the side which comes into contact with the paper. Its object is to support the sheet while it is being pressed, and it is sufficiently porous to carry away the water pressed out. The press consists of a pair of squeezing rolls, which may be of various types. One of the best arrangements is probably a granite top roll, set forward, with a rubber-covered suction bottom roll, but many machines have solid bottom rolls, usually rubber-covered. In the former case the water is drawn through the perforations, to the suction pump. The amount of water removed here depends upon the pressure, the type of felt, and the capacity of the pump. Generally speaking, it is usual to get out as much water as possible at this press, without crushing the paper, and also having regard to the bulk or thickness required in the finished sheet. The type of felt employed is very important, but no rigid rule can be stated, as much depends on the paper and the individual features of the machine.

Since the wet felt receives into its meshes fibres, loadings and chemicals, it should be cleaned while running. There are several effective methods of doing this, such as the Vickery felt conditioner, tanks of water with beaters (*batters*) in them, or rubber-covered press rolls. A paper machine usually has from 1 to 4 presses, the most common combination being two straight presses and one reversing press. In the *straight press* the paper passes through with its underside next to the felt which is carrying it, and the top side in contact with the smooth top press roll. In the *reversing press*, as the name signifies, the opposite effect is achieved. The underside of the paper, with the wire mark, is in contact with the smooth top press roll, and the web enters the press in the reverse direction to that in which the machine is running. It is maintained that this operation minimises the *two-sidedness* of the paper, arising from the fact that the top surface of the paper is smoother than the under side, since the latter has been moulded by the wire surface and drawn by the suction into its meshes; it thus reproduces an impression of the weave of the wire cloth.

The object of the presses is to remove as much water as possible from the web of paper before it is finally dried by heat, because the former is by far the cheaper method. At the same time the pressure of the rolls stiffens the sheet and improves its surface. There are, however, instances where the sheet must be as bulky as possible (such as featherweight printings) and excessive pressure at the presses is then undesirable, as it reduces the bulk of the paper considerably. Excessive pressure is also a disadvantage where the maximum opacity is needed, because pressure increases the transparency of the paper.

The amount of moisture contained in the web of paper as it leaves the last press varies according to the paper. It depends largely on the furnish from which the paper is made, as some fibres part with water much more readily than others. Wet-beaten stock retains more moisture, after pressing, than free stock. It is, however, quite common for paper to contain from 63–66 per cent. of moisture when entering the dryer section.

CHAPTER X

THE PAPER MAKING OPERATION—II

THE PAPER MACHINE—DRY END

The Dryer Section

THIS SECTION consists of a series of steam-heated, cast-iron, hollow cylinders, against which the paper is pressed by a woollen, cotton or mixed asbestos and cotton felt. These dryers (Figs. 51 and 57) are arranged in different ways according to the design of the machine, but their purpose is to drive moisture out of the paper. The water vapour is then drawn or blown away from the felt and from the pockets between the cylinders, usually by air jets, and discharged into the outside air. Roughly speaking, for every ton of paper passing through the dryer section, two tons of water have to be passed out of the machine house.

The cylinders have a steam inlet nozzle and an outlet nozzle for passing out water and uncondensed steam. They must have highly polished surfaces and must also be bored internally so that the thickness of metal is the same over the entire surface of the cylinder; otherwise uneven drying will result. Cylinders are usually fitted with doctors to keep them clean and polished. There is a bucket or other device in each cylinder to remove the condensed water and pass it out to traps. Various steam circulating systems are used to ensure that the maximum of heat is transferred from the steam to the cylinder and to assist the discharge of the condensate. The temperatures of the drying cylinders will depend largely on the nature and substance of the paper being made, the furnish, and especially on the wetness of the stock and the speed at which it is desired to run the machine. It is possible to use much higher temperatures for very thin papers made from free stock than for similar papers made from wet stock; and with papers of the same substance higher temperatures are admissible for papers made from free stock.

It is therefore impossible to lay down definite temperatures for various machines in different mills, as there are so many other factors also to be taken into consideration, such as the amount of water left in the web when it passes to the drying cylinders, felt drying facilities, and means for the removal by hot air of the water vapour expelled from the felts by the drying cylinders. In general, however, there is an upward gradation of temperature from the first

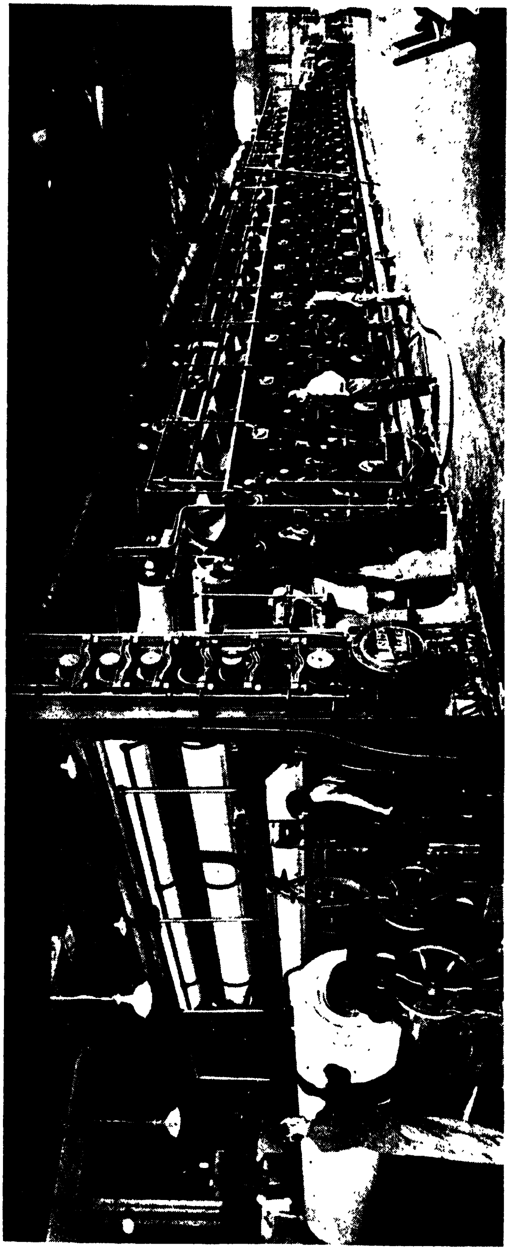

Fig. 57.—Typical Fourdrinier Dry End.

dryer onwards, followed by a slight fall in temperature at the last dryers.

The dryer felts, like the wire and the wet felts, have to be guided to prevent them running to the side and being damaged against the frames. This is achieved by a guide roll, which can be moved forward or backward at one end, thus controlling the running of the felt.

Nip rolls, or intermediate calenders, are sometimes provided just before the last dryer section to give a high finish to the paper while it is still slightly moist; they are used chiefly for papers which must have a smooth surface (as certain printings). Finishing methods are, however, discussed fully in Chapter XI.

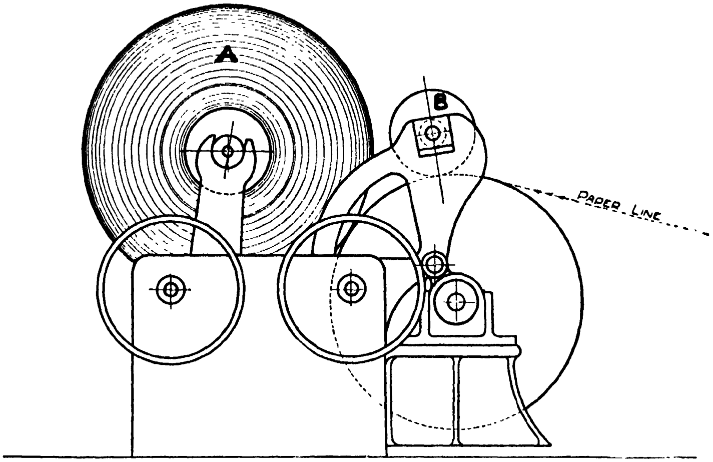

Fig. 58.—Drum Reel-Up.

A. Completed reel. B. Spindle for new reel in readiness.

Tub-Sizing.—Papers may be tub-sized either directly on the paper machine itself or separately (Chapter XI). The latter method is the more satisfactory, but if the former is used the paper is led straight from the last drying cylinder through the tub-sizing bath and then on to sparred skeleton drums, where it is dried by hot air. On some machines it is now usual to reduce the size of the air drying section by the use of high temperatures or of steam-heated cylinders. Many mills tub-size on the paper machine with a solution of starch, and this is done in a small trough before the last section of drying cylinders, in approximately the same position as the nip rolls (see above). Squeeze rolls take off the excess of starch solution, and the paper can be satisfactorily dried by steam-heated cylinders.

After the last drying cylinder, the web usually contains 3–4 per cent. of moisture. It is thus usually much drier than it would be when normally matured in air (p. 179), and in order to assist in bringing it back to its normal humidity, it is frequently passed over cylinders (*sweat rolls*) through which cold water is passed. These tend to condense a film of moisture from the atmosphere on their surface, and so transfer it to the paper; they also cool the paper and remove some of the static electricity which is often troublesome in the subsequent operation of cutting. The paper is rolled up on a wooden or steel tube revolving against a drum (Fig. 58); or on some older machines on a spindle having a hand-controlled drive, which enables an evenly wound roll to be made. When a *drum reel-up* is used, the paper automatically winds itself up at a constant tension, because the arms holding the roll gradually move away from the drum as the reel builds up.

The paper machine is driven in sections (such as the wire part, each press, and one or more sections of dryers). The control of their relative speeds is important to minimise breaking the web and setting up stresses in the paper which may result in waviness. Various mechanical and electrical devices are used for this purpose.

Running a Paper Machine

The machine man first turns on fresh water (or backwater, if available), and allows it to run through the pipes, strainer and breast box to flush out any lumps or slime, which pass out of the drain valve at the bottom of the breast box. He then closes the drain valve and allows the water to come forward on to the wire. At the same time he turns on the stuff tap, which admits stuff at about 2 per cent. consistency into the mixing box, where it mixes thoroughly with the fresh water or backwater, and so is reduced to the appropriate consistency for the substance of the paper to be made. The diluted stuff gradually comes through to the strainer, into the breast box, and so on to the wire.

As it begins to creep along the wire, the machine man lets in the clutch of the wire drive, and the wire begins to carry the stuff forward. At this stage the web is usually thinner than is required for the substance of the paper being made, and the machine man therefore gradually increases the amount of stuff until he thinks he has the correct substance. He then starts the shake motion. The stuff is usually allowed to run round the wire and into the pit under the couch (the *hogpit*) until the machine man is satisfied that everything is working correctly and that his suction boxes are properly set. He then starts the press section, and transfers the wet web from the wire on to the wet felt.

The *back-tenter* (the machine man's assistant) then takes charge of it, passing a narrow tail of the wet paper through the presses and on to the dryer section. A fine jet of water is then slowly pushed across the wire through a slotted pipe, and this gradually widens out the tail into a web of paper having the full width of the machine; this automatically follows right through to the dry end, where it is reeled up.

The machine man now obtains a sheet from the reel end, inspects it for formation (*make*) and immediately weighs it to check the *substance* (weight of a unit area). If this is too heavy he may either increase the speed of the machine (which automatically reduces the substance), or he may turn off a little stuff. Conversely, if the paper is too light he can either slow down the machine or turn on more stuff. These operations call for a high degree of skill, knowledge and experience, but a skilled machine man can usually start up his machine and make paper of the correct substance at the correct speed almost immediately.

Once the paper is satisfactorily on the reel, the machine man must make frequent adjustments at the wet end. If the formation is not satisfactory he may have to raise or lower the slice, to alter the speed at which the stuff leaves the breast box; he may alter the speed and extent (*stroke*) of the shake motion; but his best control is, as a rule, in the manipulation of the suction boxes, especially if he is making a watermarked paper. Some machine men start the dandy roll when they start the wire, by leaving the roll in contact with it; others keep the dandy roll off the stuff until the paper has settled down, and then let the dandy down to put the watermark in. No two machine men follow exactly the same procedure, and yet they can usually make a finished sheet having the same general appearance. On the other hand, each paper machine has certain peculiarities of its own and no two machines make a paper of exactly the same characteristics, even though they may appear to be identical.

The factor which has the most important bearing on the make of the sheet is the amount of water used on the wire. In some machines the wire slopes uphill from the breast roll towards the suction boxes; in others it is level; and on high-speed machines there is frequently a downward slope. These differences determine the amount of water carried by the stuff. If the water leaves the stock on the wire too soon, the sheet is *wild*; but if the water is carried too far and cannot be adequately removed before the dandy, the sheet has a crushed appearance. The happy mean between these two extremes has to be sought in order to make a sheet with a regular *look-through*.

It is apparent that the whole operation of paper making, from the breast roll to the reel-up, consists primarily in forming the sheet and then removing water from it. The consistency of stock at the breast roll is roughly 1 per cent. or less of fibre and loading. At the reel-up the web is probably about 96 per cent. solid matter, so that it is obvious that an enormous amount of water has to be removed in a relatively short time. First the water leaves the fibres and passes through the meshes of the wire cloth by gravity; then more water is sucked out by the suction boxes; some is pressed out by the dandy roll; a further amount is sucked out by the last suction boxes; and quite an appreciable amount is taken out by the couch and presses. The remainder is evaporated off in the dryer section.

Multi-Wire Machines.—It is sometimes necessary to produce a sheet of paper which is made up of two or more layers instead of one single thickness. One way of doing this is by pasting together sheets of finished paper, and *pasteboards* are built up in this way (see p. 152). At present, however, we are concerned rather with the production of such papers on the paper machine, thereby avoiding the expense of an additional operation. The object may be to produce a paper having both sides as near alike as possible, an obviously important matter in high-grade printing and catalogue papers; to produce a more uniform look-through and improved strength (especially folding) properties; or to make a paper having two sides differing, for example in colour (*duplex*).

Two machine wires are used. One is the normal type, but is set up in line with the top row of drying cylinders. The other is underneath it and runs in the opposite direction, namely, away from the cylinders. The wet web is taken off the latter wire and carried on a long felt up to the couch of the top wire, where it joins the web from the latter as both pass through the same pair of press rolls. This arrangement ensures that the wire sides of both sheets are in contact, so that the outsides are both top (or felt) sides; the top sides have the better printing surfaces.

Where the two sides must be as alike as possible, both wires are furnished from the same machine chest, and the two wire parts must be as alike as possible in all respects. With duplex papers, however, different furnishes and wire parts are used according to the type of paper to be made. A limitation of the method is that thin paper cannot be made, the lower limit being about 90 grams per square metre. The same principle has been developed in specialty mills for the manufacture of three-layer (*triplex*) and similar papers.

THE MANUFACTURE OF BOARDS

Introduction

According to British paper-trade customs, "boards" includes *cardboard*, *millboard*, *boxboard* and *stiffeners*, having a substance of more than 90 pounds per 480 sheets of double crown size (measuring 20 by 30 inches), equivalent to 220 grams per square metre. The cylinder mould commonly used in board making (see below) is often spoken of as a board machine. However, this is hardly correct, because material heavier than the above substance is sometimes made on a Fourdrinier wire machine; and, on the other hand, cylinder moulds are occasionally used for making paper. Thus the so-called mould-made paper, though not hand made, may have deckle edges on all four sides (see p. 120).

Hand-Made Boards are seldom made nowadays. Occasionally bookbinders' boards are so made, but it is doubtful whether the extra labour involved is justified. The process is similar to that used for hand-made paper, except that the mould is more robust and the deckle much deeper (up to 4 inches). The mould is not dipped into the vat, but the pulp is ladled into the mould and, after a short drainage period, it is pressed in the mould with a slab of wood fitting inside the deckle. The pressing and drying of the sheets are similar to the corresponding operations for hand-made paper.

Millboards are usually made in sheets from a layer of pulp formed on a cylinder mould (see below), and built up into plies on a *making roll*. A Fourdrinier machine could be used, but the resulting plies are thinner, and more would be required. A felt couches the sheet coming from the cylinder and carries it into the nip of a press, the upper roll of which is the making roll. This may be of wood or of cast iron, and it has one or more grooves along its length. As the sheet passes into the nip it leaves the felt and adheres, on the first revolution, to the roll itself; and on subsequent revolutions to the layer of pulp already present. When sufficient layers have accumulated on the roll a pointed stick is inserted in one end of the groove and carried quickly along the length of the roll; this divides the sheet, which is transferred by hand to a table in front of the press. Unless the board is very thick it is not usually necessary to stop the machine to remove the sheet. The size of the sheet is fixed by the width of the web and by the circumference of the making roll, though with large making rolls the circumference may be divided into two or three equal parts by as many grooves. The number of plies varies; thus a *pressboard* may have about eighteen, while a board which is to have a finished thickness of ¼ inch will be plied up to 1¼ inch thickness in the wet state.

The boards are subsequently pressed as with hand-made paper, but they are separated from one another by pieces of cotton or jute fabric instead of by woollen felts. Drying may be carried out by hanging the sheets from clips, usually in special tunnel driers through which the sheets pass slowly on wagons or on travelling chains. As with paper, care is taken to condition the dried boards before they are *milled* (hence the term "millboard"), that is, flattened and smoothed between heavy squeezing rolls. Such a process is slow and expensive and only justified for the thicker and better types of boards, such as stiffeners (for boots and shoes), pressboards, boards for cases, etc.

The large quantities of thinner and cheaper *chip* and other boards for cartons, etc., are usually made continuously from mixed waste papers on multi-vat cylinder machines, the nature and number of the plies being determined by the furnishes and the number of vats used. This important process is now described in detail.

The Cylinder Machine

This machine was invented by John Dickinson of Hertfordshire, England, in 1809, and its essential features still remain, although the general design of the vats, cylinders and ancillary equipment has been improved considerably. The essential difference between the cylinder machine and the Fourdrinier machine (p. 17) is that the making part of the former is a cylindrical wire screen revolving in a vat containing the diluted pulp. The water drains through the wire mesh, leaving the fibres on the surface of the cylinder to be picked up by a felt, which is pressed on to the top of the cylinder by a rubber roll.

The advantage of the cylinder machine for the manufacture of boards is that a number of these cylinder units can be arranged so that the fibrous mat from each is deposited as a layer, and all the layers can be combined to make a board, the thickness of which is limited only by the number of cylinders that is practicable (cf. Fig. 62). Eight-vat machines are common.

Materials and their Preparation.—Most boards of this type are used for the manufacture of containers. The raw materials are similar to those used for paper, except that they include a much larger proportion of waste papers. Many boards have plies of different fibres; thus, a strong case for foodstuffs might have a sulphite lining (*liner*) inside, and a strong kraft exterior liner, the *middle* (*filler*) being of waste papers. The cylinder machine lends itself admirably to the manufacture of this type of board.

The method of preparation of pulp for the manufacture of board does not differ greatly from that used for making paper on the

Fourdrinier machine (see Chapter VII). There is, however, some difference in the freeness required for the proper formation of the sheet in the two processes. Waste-paper fibres have already received beating treatment in the original manufacture, so that the main objective is to disintegrate them thoroughly, with as little mechanical treatment as possible, in order to preserve the maximum drainage rate. The waste-paper breaker is designed to aid removal of the various contraries which are always present; the heavy impurities (*trash*) sink to the bottom, where they are collected by a special trap and removed. The strings, rags, etc., are collected on a pronged device, which is immersed in the breaker at intervals. The waste-paper breaker usually works continuously, and the finished pulp is removed through a perforated backfall or similar device. The Hydrapulper, described on p. 94, is very convenient for processing waste papers.

After the stock has been thoroughly disintegrated, cleaned and thickened, it is ready for light beating and refining. The board mill refiner is substantially the same as that used in a paper mill, except that (to preserve the free drainage characteristics) the bars of the former are usually thinner and the operating speeds somewhat higher.

Certain grades of board must be treated in order to make them water resistant. Thus, a board which must subsequently be combined with another board or boards or which has to take a paper cover for decorative purposes, must be non-resistant to moisture to facilitate adhesion; these are soft-sized boards. At the other extreme is board for containers which may be stored in or transported under damp conditions; this must be very resistant to moisture (hard-sized boards). The normal sizing agent is a prepared emulsion of rosin size, assisted by the addition of alum (p. 104). It is preferable to add the size before the refiners (which disperse it fully in the stock), the alum being added to the pulp leaving the refiner. On modern machines it is found advantageous to control automatically the addition of alum by means of automatic measurements of the active acidity (*p*H *value*) of the stock (see p. 107). Unfortunately there is no similar method for controlling size consumption, although reasonable control can be obtained by using calibrated valves on the supply pipes; however, these must be varied in the event of any alteration in the nature or rate of flow of stock.

Distribution and Screening of Stock.—The stock from the refiner is dropped into a stuff chest. If the liners of the board consist of pulps differing from that used in the middle, a separate chest is required for each. Each chest has a pump which delivers the stock to one of two or more distributing boxes, one for each kind of pulp. This box is a wooden channel with an outlet for each cylinder of the machine, the amount of pulp flowing through each being controlled by a regulating gate; any excess is returned to the chest over a weir at the end of the channel. In this way a constant head of stock is maintained and the quantity discharged to each mould can be kept regular. The importance of this control is appreciated when its effect on the weight of the finished board is realised. As the head of stock in the box is not normally above 12 inches, a fluctuation of 1 inch (which is not uncommon) would affect the substance by about 4 per cent. In some modern machines this head is maintained automatically by means of a float, which actuates an electrical resistance governing the speed of the pump motor. Another factor affecting the substance of the board is the consistency at this stage, and on many machines this also is controlled automatically.

Each cylinder unit on the machine is composed of the *vat*, the *head-* (or *mix-*) *box*, the screen, the interconnecting pipework and the circulating pump. The screen removes non-fibrous foreign matter from the stock, and both rotary and flat types are used (see p. 81). The width of the slits varies between 0·010 and 0·030 inch, according to the quality of the board. It is essential that the size be maintained within reasonable limits, as if the slits are allowed to become widened by wear, the quality of the board will be affected. The stock enters the screen at a consistency of about 3 per cent., and is diluted at the inlet by the circulating water from the vat to less than about 1 per cent.; it is now ready for screening. The fibrous matter suitable for board making passes through the screen and into the head box, while the rejected matter (*tailings*) concentrates in the bottom of the screen bath, from which it is drawn off and screened further so as to obtain the rejects in a reasonably dry state for disposal. This is accomplished on a flat screen provided with scrapers to remove the contraries off the screen surface with the minimum loss of fibre.

The accepted stock from the machine screen flows into the mix box, which is connected by a pipe to the vat. This box levels out any fluctuation in flow from the screens; here also are mixed thoroughly the stock and the remainder of the circulating water from the vat, which is added at this stage. This is an important point, as it will readily be appreciated that unless the fibres are evenly distributed in the water and the head preserved at a constant level, the amount of fibre reaching the vat will vary, and an uneven sheet of variable substance will be deposited on the cylinder. In old machines little attention was paid to the design of this unit, but to-day it is receiving considerable attention, and undoubtedly, this is resulting in improved operation.

The Vat.—From the mix box the stock flows into the making part of the machine, the vat, with its revolving cylinder of wire screen (the *mould*) on which is formed the mat of fibre which will later be combined with similar mats to make the finished board. The vats in use to-day fall into two broad categories, the *Contraflow* and the *Uniflow* vats.

The Contraflow Vat (Fig. 59) is the older, and is in most general use. The mould turns so that its wire screen moves in a direction opposite to the flow of stock around it, and hence the name. The inlet to the vat is normally screened off from the making portion by two weirs, and in the centre of the inlet is a baffle with a space at its base, under which the stock passes. This arrangement rectifies some of the irregularity of flow caused by the right-angled turn into the vat approach piping. As a further means to this end, an adjustable baffle (having the form of an elongated butterfly valve) is sometimes installed in the first part of the stock inlet. In modern machines the design of the connection from the mix box to the vat is receiving considerable attention, with a view to eliminating these irregularities.

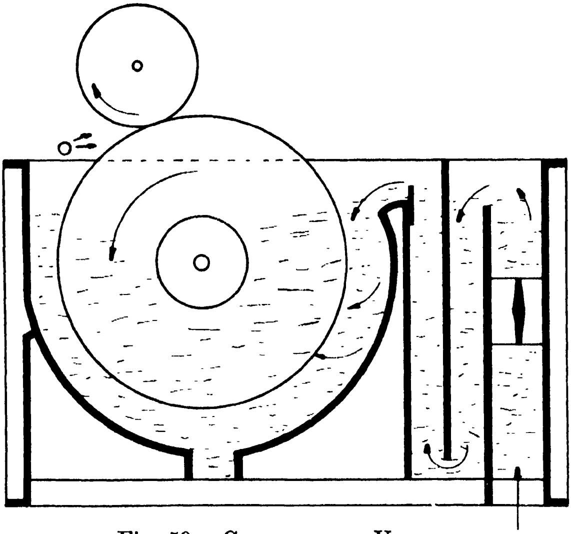

Fig. 59.—CONTRAFLOW VAT.

The edge, or *sill* of the second weir, over which the stock flows on to the mould wire, is formed by a metal strip hinged in the centre (and often near the ends also) so that it can be raised or lowered from either side of the vat, thus varying the quantity of stock passing to each side of the mould. This is called the *making slice*, and its function is to adjust the level of the sheet.

The fibrous mat deposited on the mould wire is picked off (couched) by a felt passing over all of the cylinder moulds, and pressed down on each by a felt- or rubber-covered roll (the *couch roll*). Immediately below the felt is a shower pipe, which washes the wire and so prepares it for re-immersion in the stock. The major portion of the water passing through the cylinder is drained to the circulating pump, which returns it to the screen and mix box to dilute the incoming stock. as already described. The excess of water is run away to a fibre recovery process. Regularity of formation is controlled chiefly by varying the quantity of circulating water, and in general the higher the rate of circulation, the better the formation. It is also affected by the height of the stock content in the vat, since this affects the amount of mould surface in use. It is a characteristic of the contraflow vat that a wide range of pulp thicknesses can be formed on the mould and that materials of widely differing drainage rates can be used. The adjustment of the setting for the best formation is therefore a matter of great experience.

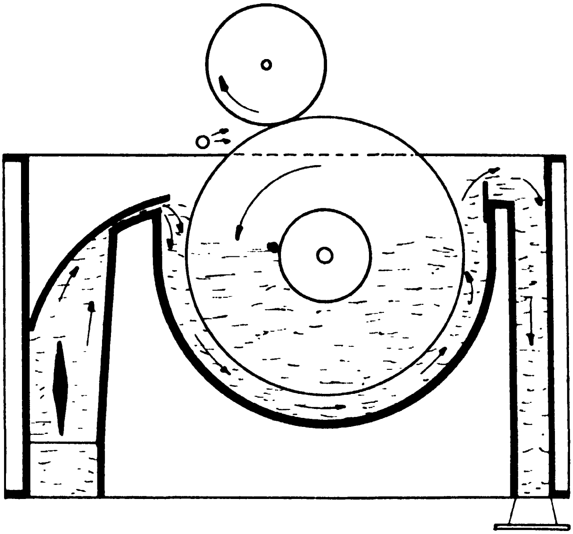

Fig. 60.—Uniflow Vat.

The Uniflow Vat (Fig. 60) is a more modern development; the essential difference is that the stock flows on to the mould wire in its direction of rotation. The flow is therefore continuous around the mould, part of the stock flowing out of the vat by an adjustable overflow at the outlet. With this method, a more regular formation is obtained, probably because of the minimum of interference with natural flow due to the above arrangement. The stock, passing continuously in and out of the vat by virtue of the overflow, is prevented from thickening locally; it is, therefore, impossible to pick up heavy layers of fibre. The contraflow vat however, has no overflow, so that extra stock fed to it can thicken up and deposit as a heavier layer.

Having transferred the first layer of fibre on to the felt, the couch roll presses out a considerable amount of water and leaves the fibre in a condition to receive the layers from the successive units, so that after the last vat the complete sheet of board is adhering to the under side of the felt. The remainder of the process is mainly that of water removal.

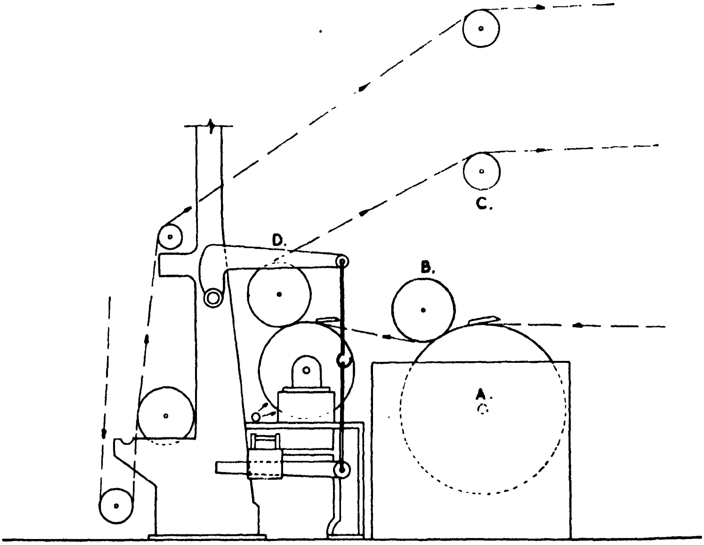

Fig. 61.—Extractor Roll.

Water Removal.—The sheet of board under the felt contains about 85 per cent. of moisture, and by careful design and operation of the machine this can be reduced by pressing to 60 per cent. or less. On many modern machines the first pressing operation is by means of an *extractor roll* (Fig. 61), a strong framework roll over which is stretched a wire mesh; it is mounted immediately after the last cylinders (A) and couch (B). The wet board is pressed on this roll by a weighted roll (D), whereupon some of the water is removed from both felt and board. In most machines the making operation proceeds in a direction away from the dry end of the machine (see Fig. 62), and after the extractor roll, the felt turns upwards over a roller (C), so that as it travels back to the presses the board is on top of the felt. Before it enters the press section, it is necessary to cover the wet board with another felt (the *top felt*) in order to protect it from the crushing action of the presses.

There are many types of press equipment, and sometimes six or more small presses are used. A fixed bottom roll is used, with a pivoted top roll, the latter having a lever system on which weights can be hung and pressure so applied. These small presses are usually followed by one or more large presses, similarly weighted. On modern machines the small presses are few and sometimes are absent, the main presses being of the suction roll type (see below). It should be noted that with all press arrangements, the weight must be applied progressively on successive presses, the first roll being lightly weighted because, at this point, the sheet is not consolidated and therefore is easily distorted and crushed.

The suction roll (see also p. 130) is a perforated metal or hard rubber-faced roll into which is fitted a suction box, arranged so as to draw water through the felt at the point of pressure of the top roll and just prior to this point. Such rolls can be heavily weighted, and pressures of up to 150 pounds per linear inch are common. Although machines having four suction presses exist, it has not been found that the suction press produces a much drier sheet than does the plain press. It is found, however, that the suction used to remove the moisture ensures that the felt enters the next press in a better condition for further pressing; this eliminates many of the troubles of the plain press and makes higher speeds possible with less risk of damage to the board structure and, consequently, of breaking the web. The vacuum required by a suction roll is a matter of controversy. It should certainly be as low as possible having in mind the output of the machine and the quality of the product, because vacuum is an expensive item of power consumption; usually it is 15–5 inches.

The suction press is usually mounted with the suction roll as the bottom roll and a rubber-covered top roll. Unfortunately, owing to the construction of the roll and to the methods of mounting and weighting, it is not possible to calculate by any known formula the amount of deflection it will undergo, so that the determination of the correct camber becomes a matter of experience and experiment. In pressing, camber is of the utmost importance, and time spent recording the effects of slight variations in camber will be amply rewarded. Naturally, it is more difficult to reduce the moisture content in the centre of the sheet, and whilst this can be

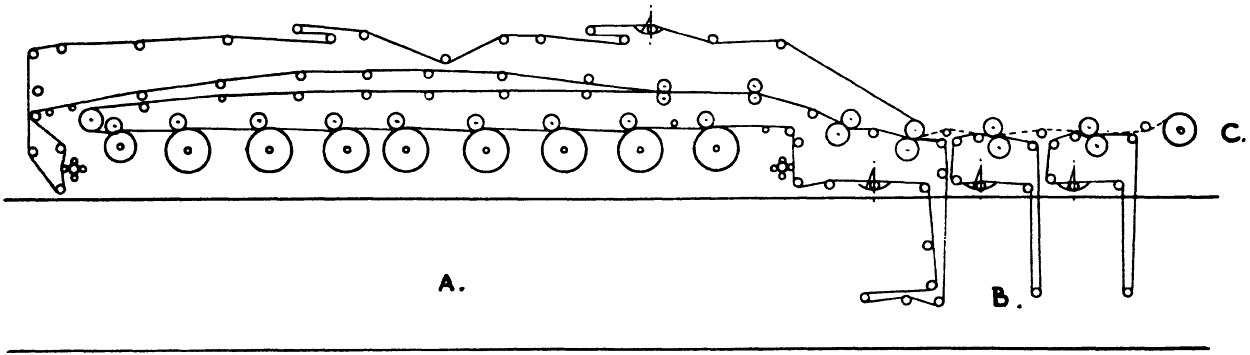

Fig. 62.—Board Machine.

A. 8-Vat portion, and extractor roll. B. Press portion. C. Wet board passing to dryers.

accomplished by extra camber indiscriminately applied, an apparent uniformity of moisture content across the pressed sheet will not necessarily result in an evenly dry sheet on completion of the drying process. Quite often a damp streak is found in the centre of the sheet after drying, which cannot be traced to a high moisture content after pressing. It is usually due to too much camber, which causes stretching of the sheet; close contact with the surfaces of the dryer is prevented, and drying therefore retarded.

One method of weighting presses is by a series of weighted (usually compound) levers. This method is being superseded by a pneumatic cylinder used in conjunction with a pressure-reducing valve; a pressure recorder with two pens records the weight on each side of the press.

We left the board entering the press section (Fig. 62). It should be noted that most of the water flows off the top of the felt at the nip of each press, and the adjustment of the guides (*slices*) provided to prevent accumulations of water on top of the felt (*ponding*) is most important. When the board emerges from the last of these presses, it is self-supporting, and at this point the top felt and the making felt are turned back to be cleaned of adhering fibre before entering the vat section again. The felt is usually cleaned by the *whipper*, a rotating spindle on which are fixed (usually) four parallel members of circular cross-section (Fig. 62). As the whipper rotates these strike the felt, and by so doing open its structure and help to restore its normal condition. This process is aided by the application of water on both sides of each felt; it is therefore advisable to dry the felt somewhat before it re-enters the vat section. This is done by a rectangular suction box of square section, often faced with metal and having slits in the metal face, and connected to a suction pump.

The sheet of board has now left the main press section, where the moisture content will have been reduced to 60–65 per cent., depending upon (*a*) the freeness of the stock (a free stock will part with water more readily than a slow stock); (*b*) the weights on the presses; (*c*) the accuracy of the camber on the presses; and (*d*) the uniformity of formation in the vats. On a board machine there are also one or more *finishing presses*, to smooth out the felt mark caused by the action of the main press on the wet sheet. They usually have a highly finished stone or metal top roll, and the sheet is carried through on a felt of close weave and even structure. Up to 1 per cent. of water can also usually be extracted at this point. The number of presses varies with the quality of the board, and occasionally the board run is arranged so as to reverse the sheet between the presses, thus bringing the highly polished roll into contact with the other side of the board.

Drying.—The web deposited on the felt by the cylinder moulds has a moisture content of about 85 per cent., that is 5·7 times its own weight. If the procedure described above is followed the moisture content is reduced to 60 per cent., which means that for every ton of board nearly 1·5 tons of water must be removed by evaporation in the drying section. One of the principal reasons why the efficiency of the pressing section must be maintained is that it is much more expensive to remove moisture by evaporation

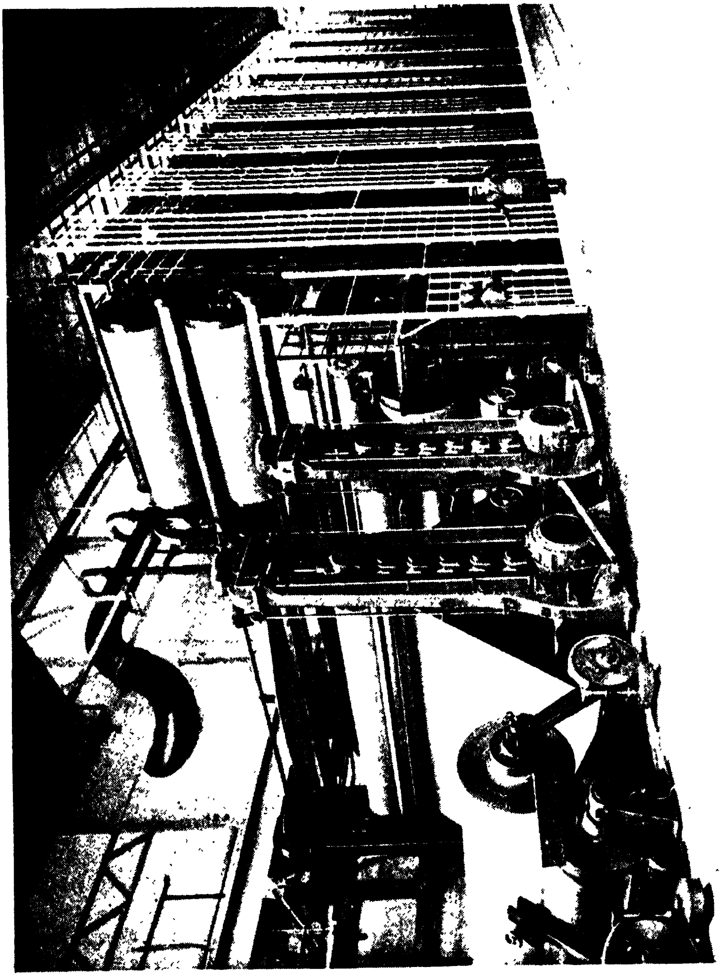

Fig. 63.—Modern Board Machine. Dry End.

than by pressing; furthermore, on many board machines the factor limiting output is the dryer section. The board is fed from the last finishing press, over a leading roll, to the dryers. Sometimes this is a hand-fed operation right through the dryer stacks, but on many machines an ingenious rope feed makes it automatic. This device is almost indispensable when large, vertical stack dryers are used.

The subject of drying has already been discussed in connection with the paper machine (p. 134), and the drying section of a board machine is similar in many respects, though usually much larger owing to the greater tonnage produced (Fig. 63). As these large tonnages are usually obtained at speeds rather slower than with paper, the syphon pipe method is nearly always used to drain the cylinders. Felts are seldom used on the dryers.

During drying, the large amount of vapour liberated must be absorbed if the maximum drying rates are to be achieved and the working conditions in the drying section made comfortable for the operators. This is accomplished by introducing hot dry air, usually through perforated pipes installed across the stacks adjacent to the dryers, especially where vapour pockets are formed by the run of the sheet over the dryer. The moist air is then removed from the actual building by means of suitable exhausting equipment. Considerable progress has been made in recent years in the design of properly ventilated machine houses which lend themselves to such treatment.

Finishing.—The board leaves the drying stack with a moisture content of 2–7 per cent., according to the purpose for which it is intended. It then has to be finished, that is, calendered and reeled, after which it is transferred to the winder to be cut and wound into reels of suitable size (see Chapter XI). There is a difference in technique in the calendering of board as compared with paper, in that very often water is used on one or more of the rollers. The purpose of this *water finish* is to soften the "skin" of the board, so that the calenders are able to produce a smooth finish. This is necessary because the board has been processed between two felts which leave an impression more difficult to remove than the wire mark of the paper machine. The water is applied from a *water box*, a trough extending the full width of the calender stack and arranged so that water flowing into the box is picked up by the calender roll. The temperature of the water in the box is important, as fluctuations result in variations in finish.

Sometimes the board has to be shipped as sheets, and the sheet-cutting process varies on different machines. In some cases the sheet cutter is arranged in line with the calenders, and the reeling and cutting is done as the sheet comes out of the machine. In other cases the reel is removed from the machine and cut separately. On the whole, however, the finishing methods are very similar to those described in Chapter XI for paper. Thick boards are made by pasting together two or more sheets of ordinary boards, in web form, just as the thinner *pasteboards* (p. 139) are made by pasting together webs of paper.

CHAPTER XI

FINISHING AND "AFTER-TREATMENT"

FINISHING PROCESSES

IN PAPER making, the *finish* of a paper is usually understood to refer to the nature of the surface or texture of the sheet, and in particular to describe whether it is rough or smooth. In the present chapter, however, it is necessary to interpret the term "finishing" in its wider sense, so as to include the principal processes which the paper normally undergoes between the reel of the paper machine and despatch from the mill. Such processes vary considerably according to the purpose for which the paper is required, but they fall under three main headings, namely, special finishes (in the above sense); "after-treatment" processes; and slitting, cutting and sorting.

A certain amount of overlap between the first of these and Chapter X is inevitable, because some special finishes are produced on the paper machine (*e.g.* water finish and M/G); however, it has been considered desirable to deal with these in the present chapter.

Factors Affecting Finish

The finish and handle of paper depend largely on: (*a*) the furnish used in beater, including the loading; (*b*) the beating treatment; (*c*) treatment of the paper on the paper machine; (*d*) finishing operations, such as tub-sizing, coating and calendering.

A good paper maker always has the finish of the paper which he has to match "in his mind's eye" before he writes out his furnish sheet. For example, a well-closed, heavily loaded sheet of paper (such as an imitation art) takes on a highly glazed surface with comparative ease, as compared with a glazed transparent paper made from a hard, greaseproof sheet. Though the final finish may be the same for each and though the methods of obtaining it are similar in principle, the latter paper requires much more pressure on the calender rolls (see below).

The mesh of the machine wire, and sometimes of the dandy roll also, may affect the finish of the paper. As a rule, if a close finish is required a fine-mesh wire is used, as a coarse wire may leave its impression on the under side of the paper; and a dandy roll with an open mesh may give a similar impression on the top side. A watermark or laid mark may also be too prominent on the surface of the paper, thus preventing the printer from obtaining first-class results.

Finish may also be affected by the texture and condition of the wet felts on the presses (see p. 132). A heavy pressure by the press rolls on a worn felt often imparts a "felt mark" to the surface of the paper. This is sometimes a desirable characteristic, for instance on a rough or matt cover paper. Low finishes, known variously as *rough, matt, antique* and *not* (see p. 122), according to type, depend mainly on the handling of the sheet at the wet end of the paper machine. The reversing or turning press, usually the last press on a Fourdrinier machine, and the wet smoothing press (*baby press*) are sometimes missed in order to obtain this type of finish in its roughest form, the paper being reeled up straight off the drying cylinders. Similarly, a fairly good matt finish can be produced by using all the presses, including the wet smoothing press, and by-passing the calenders. Offset paper, blottings,, and filter paper are examples.

The Smoothing Press usually consists of a hard top roll and a comparatively soft bottom roll, both rubber-covered; the pointed end (*tail*) of the paper sticks to the former, and is thus carried through. Its function, as the name implies, is to smooth out any irregularities caused by the wire, felts, presses or suction couch. Wires, felts and rubber rolls are subject to wear and deterioration, and a skilful machine man must be able to determine the effect of such wear on the finished paper and to adjust accordingly his "make" on the wire and his working pressure on the presses.

The average paper to-day has a smooth finish, and usually requires a felt having the closest texture consistent with good drainage through it, to ensure maximum water removal. Thus the first press felt may have a fairly open texture; whilst the felts on the second press and the third press (which is usually the reversing press, see p. 132) are closer and finer. The object at this stage is to close up gradually the surface of the paper.

Dryer Section.—In order to obtain a good even finish it is necessary to dry the paper carefully and gradually. Over-drying may produce harshness and brittleness, which are difficult to correct by subsequent processing. Under-drying causes streaking, blackening of the surface, and loss of bulk and "handle."

An intermediate, two-roll *smoothing calender* is usual for printing and writing papers. The rolls are made of highly polished chilled iron, and are steam heated. The calender is placed before the last three to seven driers of the paper machine. Pressure is applied by compound levers and weights bearing on the top roll journal ends. Great care must be taken that the drying is regular when the paper enters the calender, as it has a tendency to blacken wood pulp papers, to reduce the bulk, and to spread any particles of dust which may have been picked up by the wet sheet; however, it ensures a flat sheet of paper, free from "cockles." Esparto papers show less blackening and loss of bulk, and these rolls are therefore used extensively in their manufacture.

Machine Calenders (Figs. 51 and 64) are substantially built stacks of three, five or seven chilled iron rolls, having highly polished surfaces when in good condition. The odd number enables the paper to be threaded through them with comparative safety; also a lap of paper round the top roll is less likely to crease than if the paper is fed straight into the line of contact of two rolls (the *nip*) from a leading roller. Except for fast newsprint and wrapper machines, over the top roll and into a guarded nip is usual practice nowadays. An effective guard in common use is a rigid steel pipe or bar, 1·5–2 inches in diameter, securely fixed near enough to the nip to keep fingers out, and yet to leave sufficient space for the paper to be fed in quickly. Guards must be approved by the Factory Inspector. It is important to keep the rolls clean, and good *doctoring* is essential to prevent *stamp marks* in the paper. Good doctors also keep the rolls in condition for a longer period before they require re-buffing and polishing.

On fast machines (*i.e.* running at over 400 feet per minute) there is usually one stack of calenders. This may have up to ten rolls, and the paper is usually fed into an unguarded *black nip* from the leading roll by hand, by a rope feed, or by air jets; a black nip is a pair of rolls which, when in working position, does not allow the passage of any light when tested with a strong electric lamp. With machines making fine writings and printings all the rolls are usually steam heated; otherwise intermediate or alternate rolls only are heated. Occasionally no heat is used, and the bottom rolls are even sometimes cooled.

Machine calenders are usually driven by a variable speed drive on the bottom roll only. The other rolls in the stack are driven by friction between the top and bottom roll faces. The bottom roll (which is always the largest in diameter and heaviest in construction) is usually cambered, to an extent which depends on its diameter and length, to allow for the deflection of the metal when pressure is applied at the ends. The intermediate rolls are smaller, and are usually ground parallel. The top roll is heavier in construction than the intermediate rolls, to enable pressure applied at the ends to be transferred as evenly as possible over the face of the paper. Good lubrication of the calender ends is essential; modern machines nearly always have roller bearings.

Operation of Machine Calenders.—Machine-finished (M/F) writing papers usually have a finish ranging from *English* ("egg-shell") to fairly smooth. It is achieved by means of light, even rolling on two to four stacks of calenders, according to the degree of finish required;

the "point of effective drying" of the paper has an important bearing on the regularity, bulk and finish of the final paper. This is the point at which a slight puff of steam vapour can last be seen rising from the paper or the dryer felts. It may be at the last bottom dryer; on the last felt of the paper machine; or at any roll of the first or second set of calenders with engine-sized writings. If it occurs at the last dryer, a low finish with comparatively good bulk is indicated. As it comes nearer to the reel end, steam-heated rolls must be used; the finish is increased and the bulk decreased. This is, of course, only a general direction, and it is varied according to the particular finish desired.

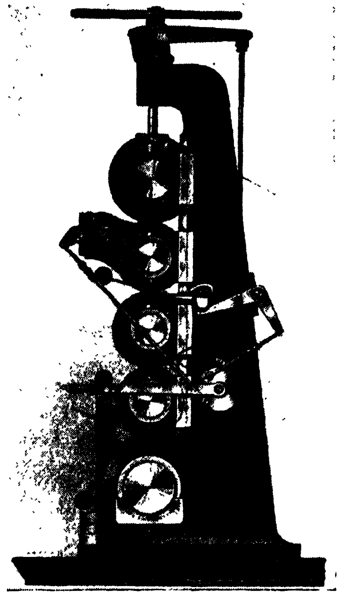

Fig. 64.—Calender with Water Doctor on Top Nip.

When a *full machine-finish* is required, four or five full stacks are used. These are usually arranged in two sets of five rolls (the first stack having rolls of comparatively large diameters) and two sets of seven rolls. This ensures a smoothing action without much slip, thus preventing the blackening tendency due to smaller rolls and slightly damp paper. The smaller is the diameter of the rolls (down to about 9 inches), the greater is the slip. Adjustable weights and compound levers are used on each side of the stacks to produce an even finish across the sheet. Hydraulic pressure is preferable for this purpose, as it can be controlled more accurately.

Water Finish (see also p. 151).—An imitation art finish is achieved on the paper machine by means of *water doctors* on the second or third set of calenders (Fig. 64). These doctors apply a thin film of water to the paper surface as it enters the nip. It is important to ensure that the paper is evenly dried across the web before the water doctor is reached; otherwise the finish will be uneven. The rolls, too, must be mechanically perfect, because it is the nip itself which presses out any excess of water. A five-roll stack is therefore desirable.

The doctors themselves consist of suitably strengthened copper or wooden trays, the backs of which are upright while the bottoms rise from the under sides of the backs (at an angle of about 25°) to within about ⅛ inch of the surface of the lower roll of the nip and about 2 inches from it. This bottom is tapered off to a rounded point, wood being used for the trays so as to allow the water to come as near to the roll as possible.

Water is fed into these trays from a feed tank, and a cock on the feed pipe and an adjustable overflow are used to maintain the level of liquid in the tray at a desired height, according to the quality and substance of the paper being made. The water may contain *plasticisers*, such as glycerin, borax, silicate of soda, or soluble starch; and even colour or wax emulsion, according to the final effect desired. It is therefore often desirable that the overflow should be pumped back to the feed tank, in which a constant level is also maintained by means of an overflow. The standard solution of chemical is added to a service tank into which both overflows deliver.

Usually a clean strip of wet felt is used to carry the liquid from the tray on to the face of the roll. This felt is folded and the ends are held down in the tray by small square bars of lead. Sometimes, to ensure good distribution, the liquid is fed on to the felt by means of a spray pipe, or in modern equipment by slotted atomisers; no felt is then needed.

Temperature control, both of the solution and of the calender rolls, is highly important. The rolls tend to cool, but should a break in the paper occur, care must be taken that the stack does not get too hot. A thermostat is therefore useful here. At least two stacks of seven steam-heated rolls are required to finish off paper so treated, and the pressure on each must be accurately regulated so that the sheet receives a gradual increase in pressure.

M/G Finishes.—The chief characteristic of *machine-glazed* (M/G) papers is an even, high glaze on one side of the paper. This is obtained on a large drying cylinder (Fig. 65) of the paper machine by pressing the semi-wet web (containing 70 per cent. of water) and the wet felt between heavy, rubber-covered press rolls and the cylinder. This causes the sheet to adhere to the hot cylinder, which both dries the paper and glazes it. The paper is dry and comes away cleanly after making about two-thirds of a revolution, with the glaze on the side which was in contact with the cylinder.

A *plain M/G finish* is usually made with a strong, closely woven (*superfine*) felt, whilst any design or rib is pressed into the sheet by special felts or by patented engraved or turned rollers following a plain felt. Certain papers, such as coarse wrappers and cellulose wadding, are merely dried on an M/G cylinder because it is the most convenient method of handling them; the finish is unimportant.

The most important factor so far as finish is concerned is a clean and highly polished cylinder surface; scratching and pitting must be avoided. The methods of achieving this are many and varied.

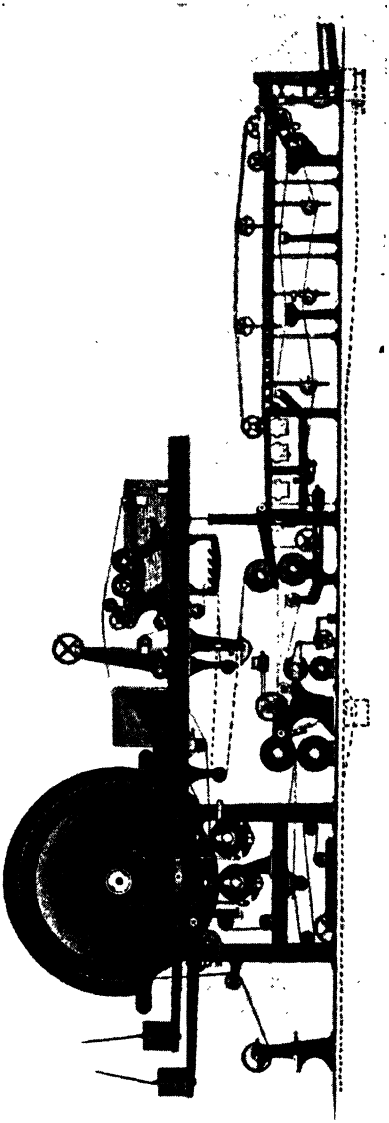

Fig. 65.—M/G Paper Machine.
Ordinary Fourdrinier wet end at right; the wet web passes through press rolls and over the large dryer, to the reel.

Oscillating doctors of all designs and materials, from steel to lignum vitae, are used; and two are usual. Fine emery cloth, a revolving wire burnishing brush, or a fine spray of hot alkaline water followed by a low-pressure felt doctor are also used.

Clean sulphite paper, free from much loading, probably produces the highest finish, although pure krafts, envelopes, and poster papers all give good results. It is difficult to obtain a good flat finish with wet stock except in light substances. Freely beaten stocks usually show a fairly good finish in heavy substances.

Finishing Hand-Made Papers

As these come from the tub-sizing process (p. 168) they are sometimes pressed hydraulically, heavy zinc plates being inserted between about every 500 sheets to flatten them (*cold pressing*). From thence the paper is taken to the platers, who finish it.

Rough drawing papers and photographic mounts are press finished (*not* finished—see p. 122). *Hot plate* (or pressed) finish was originally produced in hydraulic or screw presses by heating burnished zinc or copper plates, inserting the sheets between the hot metal plates alternately, and pressing hard (3 tons per square inch) for 24–48 hours. Apart from the rough or not finish, all sheets are nowadays finished on cold plates, boards or single sheet calenders.

A *wad* is made up of about a quire of alternate plates and sheets, and this is fed between two heavy rollers about an inch apart, the top roller being loaded. The rolls reverse when the wad is through, so that it may pass two, four or six times between the rolls, giving whatever finish is required. As may be imagined, there is a fair amount of slip over the plates in the wad, and this enhances the glaze on the paper.

For certain finishes boards of various degrees of finish are used instead of plates between the sheets of paper. Plates lined with cloth such as linen, and engraved plates, are also used to impart surface patterns to the paper. However, the principle is always the same. Very large sheets of drawing paper are finished in this manner, and it takes two strong men to lift the wad from the bench to the plater. Gloves are generally worn by all who handle the plates as a safety measure, and also to prevent the plates being marked by the fingers. The roll nip is usually guarded on both sides by means of a stout piece of wood, which allows only the wad to pass through.

Supercalenders

These (Fig. 66) give a higher finish than is obtainable on the paper-machine calenders (p. 155). They usually have eight to fourteen rolls (*bowls*), but whereas the chilled iron rolls on machine calenders exert comparatively little slip on the paper surface, the alternate bowls in a supercalender stack are resilient and so produce much more polish. The stack is driven by a variable speed drive through a flexible coupling on the second or third chilled iron roll, and the intermediate alternate bowls are filled with compressed cotton and/or linen papers, or sometimes (for glassine calenders) with asbestos-cotton paper. Halfway down the stack are two filled bowls placed together, so that each side of the paper comes alternately in contact with the steam-heated chilled iron and filled bowls, and vice versa. A modern glassine calender stack has eighteen rolls.

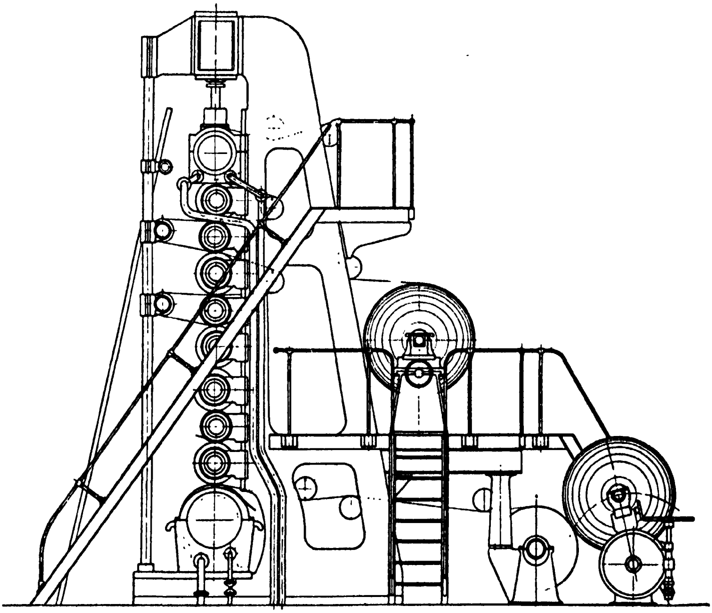

Fig. 66.—SUPERCALENDER.

The finish is usually matched against a sample, and in attaining it the quality and substance of the paper to be finished are the first consideration. This remark applies to all finishing operations (see p. 153). It is therefore important to maintain accurate records of all settings and temperatures of the damping and calendering machines for future reference. The paper has first to be damped, just as clothes must be damped before ironing. The degree of damping varies according to the amount of finish required, namely from 5 to over 20 per cent. of water on the weight of paper. Damping is a simple operation, and is achieved by means of a brush-, spray- or splash-damper on the paper machine, which wets the paper from above before it is reeled; or by a separate brush-type damping machine. In the latter, water at a constant level in a bath is lifted up to the brush by means of an adjustable copper roller driven by a variable-speed device; it is thus possible to apply accurately a predetermined amount of moisture for a given speed.

The principal objectives are to obtain as fine a mist as possible from the damping machine, and to apply it as evenly as possible across the full width of the paper web before this is reeled up. As the paper is reeled, the moisture is transferred to its other side. Boards and highly glazed papers are sometimes damped on both sides, but for ordinary glazed finishes damping on one side is considered sufficient. Even reeling is very important with all classes of paper, as otherwise "skidding" due to uneven tension results on re-reeling. It is desirable to allow the damped reel to stand for 1 hour or more, according to the type of paper, to allow uniform penetration. When a high finish is required on a hard paper (as with glazed transparent paper), the damped reel is allowed to stand for some 12 hours, and the edges are protected to prevent drying-out. With a low percentage of water a "slack" glazed paper is obtained by a light rolling action using only three to five nips between the rolls of a slightly warm calender, the other rolls in the stack being missed.

A *rolled finish* (as for index boards) is obtained by fairly light damping and light rolling, using all the rolls; or by using pressure and a few nips with a slow running calender.

The pressure on a supercalender is obtained either by compound leverage and weights, or hydraulically. The slip between the rolls is governed by the speed at which the calender is driven and by the pressure applied to the top roll, and from there on down the stack. Great care must be taken to keep the bowls clean and unblemished. The filled bowls are easily damaged, even when idle, if they are under pressure or are heated. When in use they should be washed carefully twice daily, and lubricating oil must be kept away from the edges.

The quality and loading content of the machine-finished paper must be taken into account. Papers with a high china clay content can acquire an exceptionally high finish, but lose about a third of their bulk in the process (*e.g.* S/C printings and imitation arts). Glazed imitation parchment (G.I.P.), though as highly glazed, requires rather more damping in proportion to its substance, and a fair amount of pressure, because the original paper is hard. Actually, there are as many finishes as there are paper qualities, but a supercalender can usually match any reasonable finish higher than machine finish.

Supercalender operation entails knowledge and skill. Ladders in front of and behind the rolls have to be climbed in order to feed the paper through the machine, and a slip may mean a nasty accident. Good health and footwear, clean machines and floors, and good lighting are the best indirect safeguards. The nips on the supercalenders are always guarded, either with angle irons or, preferably, with steel bars $1\frac{1}{2}$–2 inches in diameter.

Friction Glazing is generally carried out on a three- to five-bowl calender of very strong construction, adjacent bowls being driven by gear wheels at speeds which differ in the ratio 1 to 2 or more, so that the paper passing between them is subjected to the combined effects of friction and pressure. A three-bowl calender has top and bottom chilled iron bowls, with a paper-filled bowl in the middle; and a five-bowl calender has three chilled iron, steam-heated bowls and two paper-filled bowls. The paper is damped so as to contain 8–15 per cent. of moisture, and is fed directly into the first nip. On the top iron roll is a *wiping roll* covered with felt; wax is applied to the top of the bowl, and the wiper spreads it so as to coat the surface of the sheet evenly as it passes through for the first time.

If a paper is put through a friction calender three or four times, a very high finish can be obtained. The resulting paper is mostly used nowadays for confectionery work and for wrapping fine cutlery and chemical apparatus. When a very high finish is required on a wrapping paper, the wax is often omitted, and the resulting finish is similar to that obtainable on a large supercalender. Friction calenders can also be used for coated papers (p. 170), in which case any wax used is often incorporated in the coating mixture.

Flint Glazing is accomplished by means of a highly polished flint stone which passes backwards and forwards, under pressure, across a web of paper (usually 20 inches wide) moving slowly over an iron table. The stone takes the place of the cross-head of a crank-shaft fitted to a wheel 20 inches in diameter. The stone is also connected to a vertical shaft, to the top of which weights are added according to the degree of the burnishing required. There is still a limited market for such paper, which at one time was used almost exclusively (especially on coated papers) for box coverings and cover papers.

Embossing.—Paper to be embossed on the reel is first damped in the usual manner with 5–15 per cent. of moisture, according to the final depth of the embossing. Products such as cellulose wadding are not damped, but are usually embossed three or four plies together after creping (see below).

The embossing calender may have two to five rolls, the two-roll calender being the most common. It consists of an engraved steel roller carrying the design, and a larger paper-filled roller geared to it exactly, so that at each rotation the pattern contacts exactly the same position on the larger bowl. Sometimes there is a small copper drying cylinder immediately after the embossing nip. Paper serviettes and table "cloths" often have to be cut so as to register with the embossing. The principal use for embossing of this type, however, is for decorative wallpapers, fancy packings and box covers.

With a three-bowl embossing calender the steel engraved roller is in the middle, with two large, paper-filled bowls geared to fit the pattern. This type of calender is used mainly for tissues, serviettes and such products, where a comparatively free stock is used. A five-bowl embosser usually has an engraved roll between two paper-filled bowls, with heavy, plain, chilled iron rolls at the top and bottom, the lowest and heaviest being the driving roll.

The paper bowls have a slow lateral movement to prevent the transfer of the mark of the engraving to their surface; this may amount to ¼ inch each side, or more. Such a calender is used for embossing overall designs such as for cover papers and Christmas cards, and a variety of finishes can be obtained by giving the paper more than one nip in the middle of the calender, or by putting it through the calender under full pressure. The calender is driven from the bottom chilled iron bowl, and with a plain bowl in the middle it can be used for finishing narrow reels. Pressure is applied hydraulically, by compound levers and weights, or more usually by means of a large screw and hand-wheel. It is usual for all the iron and steel rolls to be steam heated.

Imitation watermarks may be put into paper by means of embossing calenders; *linen facing* and other surface textile effects are also produced in this way (p. 159). *Corrugating* is similar in principle, except that the paper is actually bent at the corrugations instead of being just pressed, as in embossing. The machine may be likened to a pair of large intermeshing cog-wheels, between which the damp paper or cardboard passes.

Creping.—Damp paper is passed round a heated cylinder (*e.g.* an M/G dryer), from which a creping doctor removes it at a speed less than that of the cylinder; a creped effect thus results. The degree of creping is controlled by the angle at which the doctor is set to the cylinder face and the speed of the reel which draws the web away; the latter is varied by means of a cone-pulley device. The damping water may contain up to 2 per cent. of dissolved glue to set the crepe. Coloured papers are made by passing the web through a bath of dye before it is creped.

Slitting, Cutting and Despatch

Slitting and Reeling.—On the usual type of slitter and reeler the web of paper is fed from a laterally adjustable stand on which the reel can be "braked" (according to its size and momentum) when being unwound at high speed (Fig. 67). It passes through about three adjustable rollers, the middle one of which is a tension roller holding the moving web closely and evenly over a table carrying an upper and lower set of adjustable circular knives.

The lower knives are usually driven on a rotating shaft and the top knives are driven by contact with them, being set at a very acute angle to the knives on the rotating shaft. This is known as a *shear cut.* The paper then passes rapidly to the reel, which has an expanding mandrel covered with cardboard *centres* cut to the exact widths of the reels. This mandrel is driven by contact with a drum, which is adjustable to keep the bulk of the paper even. The deckle edges are removed as shavings by a knife at each edge. An ordinary modern mill reeler can make reels about 3 inches wide, although about 8 inches is the more usual minimum.

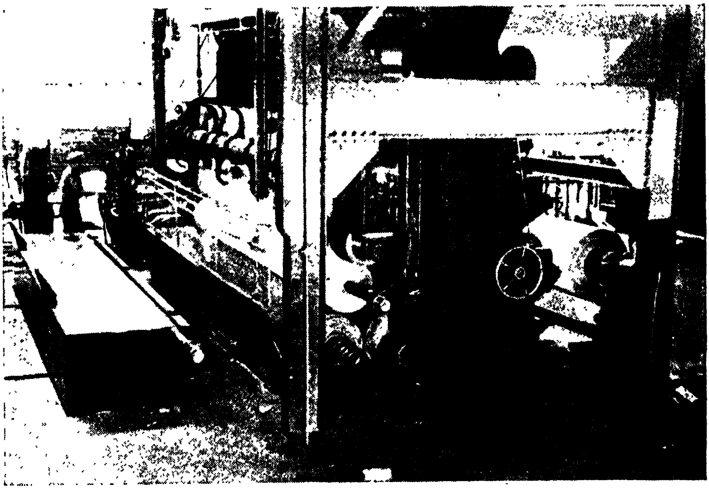

Fig. 67.—Slitter and Reeler.

Original reel at right ; slit reel at left with circular slitting knives just above.

In the *scored* or *crush cutter* a very sharp knife is pressed on to the paper as it passes over a case-hardened, chilled iron roller. This is excellent for large reels of wrapping paper and also for cutting waxed paper, as the knives can be kept very close to the finished small reels; this prevents any lateral action and gives a cleanly cut roll. It is very important, however, that the knives should be kept in first-class cutting condition and that the chilled-iron roller is not allowed to become scored, as this tends to make dust during cutting.

Cutting.—Paper is usually cut from machine reels on a rotary cutter (Fig. 68). The finest writing papers are ***cut to position*** or ***to register*** on a single-sheet cutter, a relatively small machine (up to 120 inches wide), and the sheets are cut so that the watermark comes in its correct place on a quarto sheet (or other sub-division of the parent sheet) when this is guillotined down to a usable size.

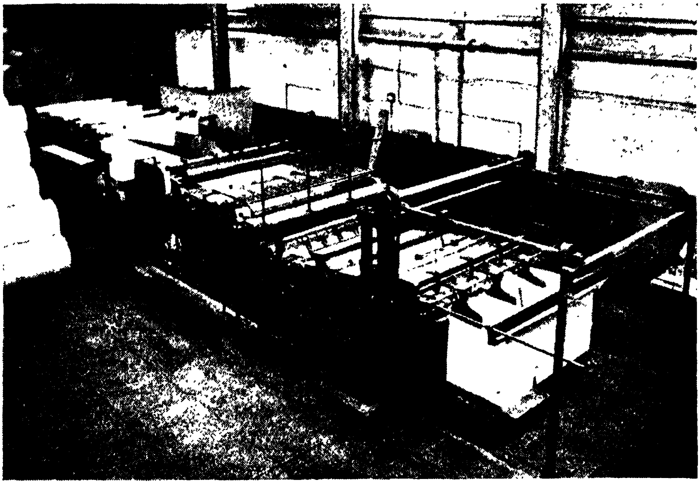

Fig. 68.— SLITTER AND CUTTER.

Original reels at back-left. The combined webs are first slit, then cut, and the sets of sheets carried on webbing belts to the lay-boys at the right.

The speed of the revolving knife can be finely adjusted to the rate of travel of the paper by means of a hand-wheel, which varies the diameter of the pulley driving the revolving knife.

Ordinary printing papers, such as supercalendered printings, wrappings and other plain papers, are usually cut on large *duplex* cutters. It is always desirable to make paper so that it occupies as nearly as possible the full width (*deckle*) of the paper machine, but when the size ordered makes this impossible, it is usual to proceed as in the following example. Suppose sheets 30 × 40 inches are to be made on a machine 100 inches wide. Then two 30-inch and one 40-inch reels are made. After slitting, the two 30-inch reels are chopped into sheets 40 inches long by one knife, and the 40-inch reel is chopped to 30 inches by the other knife. However, this is undesirable for certain printings (see p. 177).

Up to twelve rolls can be cut at once, depending upon the thickness of the paper. The paper is loaded on to a stand at the back of the cutter, and is then fed through a pair of heavy nip rollers, which must be carefully guarded. Then it is drawn through a pair of finer rolls, through the slitting knives (which can also remove the deckle edges as shavings), and on to a short table which carries the stationary (*dead*) *knife*. Sometimes the loading-up stand is in two sections, one of which is loaded while the reels on the other are being cut. When the latter are finished, the whole stand revolves on a turntable, so as to bring the new rolls into position without loss of time.

Fig. 69.—Sorting and Counting Finished Paper.

The speed of the rotating knife may be varied to chop between, say, 15 and 120 inches on a big cutter. This is done by adjustable gears, by changing the pulley wheels, or by increasing the diameter of a rope-driven pulley working on the two-cone principle. The cut sheets fall on to a felt or tapes, and are then guided into an automatic sheet catcher (*lay-boy*). This "jogs" the sheets automatically into even stacks. On high speed machines the sheets overlap as they come down the tapes.

Envelope papers are usually cut into a parallelogram to allow more envelope blanks to be produced out of each sheet. This is done on an *angle cutter*, the drive on the rotating knife being on a bevelled gear. The other end of the shaft of the rotating knife rests on a cast-iron arc, which allows the knives to be set at any angle from 90° to 30°.

Sorting, Counting and Parcelling.—From the sheet cutters the paper is taken on wooden *stages* or *skids* to the paper sorting department or *salle* (Fig. 69). Women are much better at sorting than are men, and their chief duty is to examine each sheet of paper carefully and to grade it or reject it according to the standard required by the customer. It is an operation which can be done at a relatively high speed by an experienced sorter. She either *up-ends* the sheets (with wrappers), that is, picks up each corner in turn and lets the sheets fall quickly through the fingers; *fans* them (for instance, with printings and cheap writings) by holding a wad of paper at a top corner and twisting the hand quickly so that about half an inch of each sheet is exposed to view fanwise (see Fig. 69); or *overhauls* the better grades of paper (see below).

Watermarked writings and coated and other high-grade papers are examined on both sides. Points to be watched are variations in substance, bulk, finish and colour, as well as the presence of defects such as dirt, creases, torn sheets and bad look-through.

Usually a woman works in front of a strong, large bench, about 30 inches high, with a pile of paper on her right, and she draws (or *overhauls*) one sheet at a time from the pile into the space to which it belongs. She has a space for "perfect" paper immediately in front of her, with *first retree* (minor faults) on her left, *second retree* at the back of her bench behind the perfect paper, and a receptacle for unusable paper (*broke*). Both hands are used, and a good sorter can keep a continual stream of sheets moving before her, grading them into good, mediocre and bad.

The sorted paper is taken to the *finisher*, who overlooks the sorting and fans out the sheets and counts them into *quires* of 25 (formerly 24) sheets very nimbly, with the fingers. Thus, seven fingers are used to count a quire, the first four taking four sheets each, and the last three, three sheets each. There are usually twenty quires in a *ream*.

It is usual for both sorters and finishers to check the average substance of the paper by weighing some sheets from the reams should occasion arise; it is, however, a routine duty for the finisher to weigh a full ream once every twenty reams or so, as a general check.

The sorters of fine watermarked papers actually turn over each sheet and examine the watermark and look-through as well, whilst two-sided art paper is sorted twice, once for each side of the sheet. Should the paper vary in shade, each shade is made up into separate reams. Most writings and small sizes of printings are sorted in the large sheet, which is then cut by *guillotine* into the ordered sizes. Fine printings and art papers are often trimmed by guillotine round all four edges to enable the printers to obtain perfect register.

Many mills to-day cut down the second retree to quarto size and re-sort it; this is usually done by salle learners.

The paper is finally taken in reams, on a transporter stage, to the parcelling and bundling department, where each ream is wrapped, labelled and secured with string or strong gummed tape or sealed into shipping parcels ready for the customers' use. It is sometimes necessary to protect the corners and edges of the paper by placing stout strips of paper along the edges of the reams.

"AFTER-TREATMENT" PROCESSES

Tub-Sizing

Hand-made Papers (see also p. 121) are sized with a solution containing 7–10 per cent. of skin gelatine and 3–5 per cent. of potash alum on a sizing machine which consists of a wooden or copper-lined iron bath (*tub*) about 12 feet long through which two open, but fairly finely woven, close-napped, endless felts carry the sheets, which are always *waterleaf*; that is, no size is added during manufacture. The sheets are laid on the bottom felt in pairs across the machine, and are squeezed between the felts by a pair of press rolls. The sizer room should always be fairly warm and not too dry. The wet sheets must never be chilled (by cold draughts).

The bath is kept at 103°–130° F. by means of hot water circulating in coiled copper pipes on the bottom; the felts moving through the bath keep it well mixed. Bank papers are often sized at 103° F. with a weak size. After standing in the wad or pile, which is shielded from draughts by means of a felt covering, the sheets are *parted* and pressed between boards overnight, the edges still being protected from drying. Next day they are parted once more and hung in the loft to dry.

Most papers nowadays are dried flat on coarse hessian, though some are still dried in *spurs*, two to four sheets (according to substance) being placed on cowhair ropes on a frame (*trebble*). Boards are dried singly, being hung on ball clips in a *loft* (see p. 121). Papers sized with gelatine, which is of animal origin, are sometimes described as *animal tub-sized*.

High-Class Rag, Wood and Esparto Papers.—A 4–8 per cent. solution of gelatine in water, containing 3–5 per cent. of potash alum, is used. From 0·1–0·75 per cent. of *formalin* is usually added to harden the gelatine after drying and to preserve the surface against mould growth. Although the highest grades of papers are usually waterleaf before tub-sizing many of the commoner fine papers are from one-half to three-quarters engine sized, and are tub-sized with a mixture of hide gelatine and soluble starch. The average paper takes up about 5 per cent. of its weight of dry tub-size.

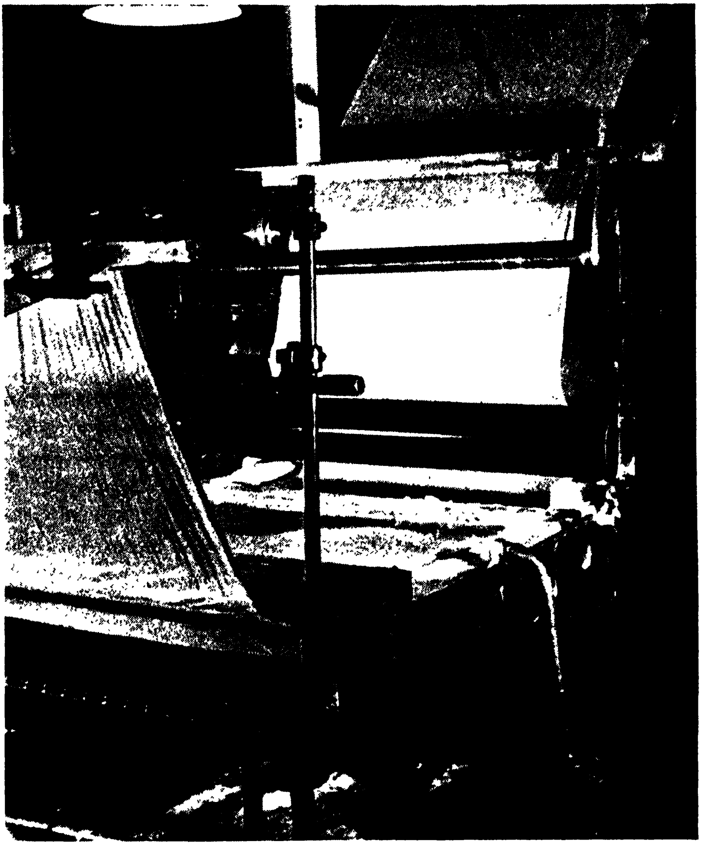

Fig. 70.—TUB-SIZER.

Tub-sizing is a highly skilled occupation inasmuch as many variables must be allowed for, such as the substance and the freeness of the paper, the degree of engine sizing, the strength and viscosity of the size, the *p*H value (see p. 142) of the size, the temperatures of the paper and size, the tension, rate and duration of immersion, and the amount of pressing. The sizer man must also decide whether to reel the wet sized paper, to allow the size to penetrate into the sheet (to maintain the sizing after erasure), or to pass it directly to the dryer without reeling. The period of immersion is varied according to the paper being made. As a guide it may be stated that at 135° F. hot, viscous size penetrates thick substances and at 100° F. cold weak size coats thin substances of paper. The size is prepared by soaking the gelatine before dissolving it by warming. This is important, as it keeps the gelatine in its stronger (gelatinous) state.

The tub itself (Fig. 70) is usually an oblong copper bath, with wooden rollers for carrying the paper through. It has a double bottom and sides, which are filled with water, and in which is a steam coil having a thermostatically controlled valve; this keeps the temperature of the size constant. On a modern sizer, to allow flexibility, there are about seven size rollers and four dipper and three upper wooden rollers, which are mounted on ball bearings and belt-driven. It is important to prevent frothing, and the paper should therefore always enter and leave the bath vertically.

Air drying must be carried out very carefully, and it is usual to have two to four steam-heated drying cylinders at the end of the sixty or more *spar drums* (diameter, 4 feet) through which warm to hot dry air is circulated according to the speed of the machine. If a low finish is desired the paper is usually dried hard (to contain about 3 per cent. of moisture) and calendered on a machine calender at the end of the drier; whereas if a high finish is required, sufficient moisture (7–10 per cent.) is left in the sheet to enable the finish to be obtained on a supercalender (p. 159) without damping.

Tub-sizing is sometimes carried out on the paper machine (see p. 136).

Coating

The principal object of coating paper is to level up the minute hills and valleys on the surface by covering them with a layer of fine mineral matter. Many modern illustrated books, magazines and catalogues are printed on such paper, because it reproduces illustrations from fine screen blocks very faithfully. Coatings are applied in the form of a suspension of a fine mineral pigment in a solution of an adhesive; the latter serves to bind the pigment to the paper surface.

The best type of coating is *blanc fixe* (artificially prepared barium sulphate, $BaSO_4$); this is used alone or mixed with china clay or *satin white* (a mixture of alumina and calcium sulphate made by mixing a solution of alum with lime water), with an alkaline solution of *casein* as the adhesive or *size*. All coating mixtures (*slips*) should be carefully sieved, as large particles on the paper cause scratching. Good quality china clay, precipitated chalk, titanium dioxide (for opacity and whiteness), zinc oxide and lithopone, with ultramarine, paste blue, natural earth and metal oxides and chromes (for producing coloured effects) are all used in appropriate proportions.

Casein is the curd which separates when milk is made acidic. It is removed, washed, dried and ground, and the resulting powder is soaked in water and then warmed with a solution of an alkali, such as ammonia or borax (*cutting*). The solution so produced is mixed with a slurry of the pigment, usually while it is still warm, the proportion of pigment to casein ranging from 4 to 10 parts to 1, according to the type of paper. Solutions of hide glue or of prepared starches are also used, but these substances are less resistant to water than is casein, although starch is very much cheaper. Other auxiliary substances occasionally added to coating slips are wax emulsions (for friction glazed papers, p. 162), foam reducers (such as pine oil) and wetting agents.

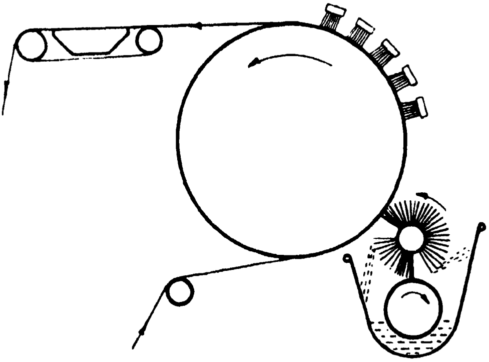

Fig. 71.—COATING MACHINE.

Diagram of coating end, showing application of coating to paper by a rotating brush.

One-sided Coater (Fig. 71).—The *body paper* is fed on to the face of a large drum about 4 feet in diameter, and the coating applied by means of a plain type printing roller partly immersed in a trough containing the coating (which takes the place of ink). Alternatively it is applied by means of a felt or brush (which picks the coating up from a roll revolving in the coating slip) or by fine spray nozzles. The amount of coating is regulated by the pressure applied to the rollers and by the depth of the roll in the bath. It is then evenly distributed over the surface of the paper on the drum by means of four to eight laterally oscillating brushes in series. The first of these are relatively coarse; the last are of very fine badger hair. The paper is then drawn over a small suction table and formed into festoons hanging on wooden rods (*sticks*). The paper is thus carried forward in loops, about 10 feet high, through a long drying chamber in which air at 90°–140° F. circulates (see below, and Fig. 72). The paper is then reeled up, but sometimes it is brought back in festoons to the starting-point before reeling. This method is useful when a long building is not available, and it also enables the operator at the coating end to see the paper as it is reeled up, and the results of any adjustments he may make.

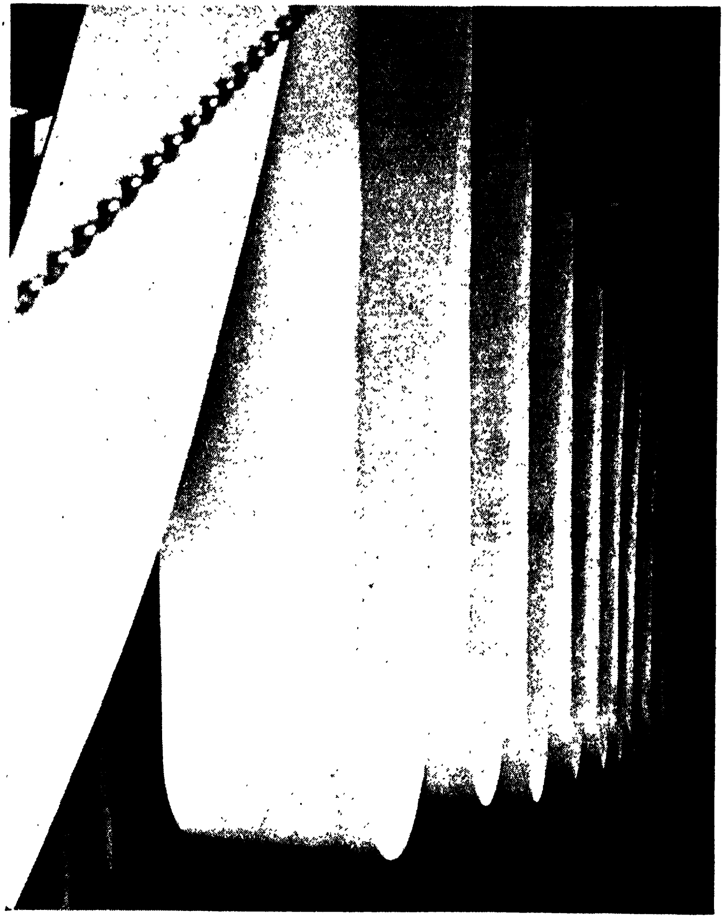

Fig. 72.—Drying Coated Paper in Festoons.

A Double-Sided Coater has two sets of application rollers, brushes or sprays; or the web may be passed through a bath containing the slip. The oscillating brushes are applied one against the other, above and below the paper. This is then carried forward horizontally for about 70 feet on jets of hot air, until the under side is dry enough not to mark when the paper is carried up in festoons looped over the carrying sticks.

In the *roll coater* the coating is applied to the paper web as it passes over a rubber roll, by means of a larger and more rapidly rotating roll, which dips in a bath of the coating slip and revolves in the same direction as the rubber roll. At the point at which the web passes between the two rolls and is in contact with both, there is therefore a wiping effect, which removes the excess of coating and smooths the surface; brushes therefore, are not usually required.

In a recent coater the brushes are replaced by a transverse jet of air, which removes the surplus coating and evens out the remainder. An enclosed, horizontal drying chamber, at about 300° F., in which the paper is maintained in suspension by means of air jets on both sides, followed by rollers, replaces the festoon system. Speeds of up to 700 feet per minute are thus obtainable with little sacrifice of quality as compared with the festoon machine, which runs at about half this speed.

It is usual to dry the coating in about two-thirds of the length of the festoon section by means of hot dry air, and then to cool the web and condition it with steam rising gently from pipes on the floor. The reeled paper is finished on a five- to seven-bowl supercalender, the bowls of which, especially those filled with paper, should be in first-class condition to prevent markings on the paper. Brush hairs from the coating machines can be troublesome here.

The calenders usually have seven bowls for single-coated papers, and eight bowls for double-coated papers; friction glazing (p. 162) is often used, and less frequently flint glazing (p. 162). It may be necessary to supercalender the paper three or four times in order to get the best *art* finish.

Brush-Finished Art Paper (*Enamel*) is usually one-sided, and contains satin white. It is finished in a brushing machine consisting of one large, circular brush made of fine hair bristle, surrounded by eight to ten rollers, five or six of which are in contact with the brush. The paper is interlaced between the rollers, which are adjustable with respect to the face of the brush. An enclosed ventilation and trunking system connected with a fan takes away the fine dust; care must be taken when burnishing chrome-coloured papers to ensure that this system does not leak.

Chromo Paper is a relatively heavily coated paper, of heavy substance, used for fine lithographic work. Coated papers for printing illustrations are known collectively as *art papers*. They are not to be confused with *imitation art papers* (p. 31), the loading in which is added in the beater, and therefore is distributed throughout the thickness of the sheet instead of being on the surface. An intermediate class is *machine-coated paper*, referred to on p. 31.

Gumming is sometimes carried out on a one-sided coating machine with a festoon drier. Nowadays, however, it is more usual to apply the adhesive by means of a rotating roller, which is partly immersed in a bath containing it, and so transfers a layer of it to the surface of the paper passing over the roll, as in a dry-waxing machine (below). The paper is then carried by rollers (in contact with the ungummed side) through an enclosed heated chamber, and it is reeled up when dry.

Grades of gummings include kraft paper, with strong glue as adhesive (gummed tape for parcels, and unsuitable for licking); ordinary paper with *dextrin* adhesive (for labels and envelopes); and high-grade, thin rag paper with *gum arabic* as adhesive (for postage stamps). Owing to the tendency of such adhesives (and especially glue) to shrink when drying, these papers curl when cut. It is usual to offset this by passing the uncut web, under tension, round the edges of two blades set so as to cause the web to travel in a zig-zag course with its gummed side outwards. This operation (*breaking*) produces fine cracks in the gum layer.

Waxing has as its object the closing of the air-spaces of the paper with wax, so as to render the paper waterproof. It does not normally produce greaseproofness, and ordinary waxed papers do not prevent penetration by water vapour.

The ordinary waxed wrapping paper is made by passing the paper from the reel through a bath containing hot molten paraffin wax, and then between rolls which remove the excess. Adjustments of the temperatures of the wax and of the press rolls serve to regulate the amount of wax taken up by the paper. The wax is usually heated by a steam coil or by hot water in the false bottom of the bath, using a thermostatically controlled valve. The paper is quickly chilled off after it leaves the bath, either by passing it over a cooled cylinder or by drawing it quickly through a cold water shower or brine bath, the temperature of which is also controlled. This gives a glazed, unbroken surface finish, although the paper is also impregnated with wax throughout its thickness.

In *dry-waxing* the paper is only impregnated with wax and has no surface layer. It is preferred when the waxed paper has to be printed or used with adhesives, although it is of course less waterproof than the paper made by direct immersion. The two types are easily distinguished, since it is not possible to remove wax from the surface of dry-waxed paper with the finger-nail; the feel and handle of such paper is preferred by many users.

The paper is passed between two rolls, the lower of which is partly immersed in a bath of molten wax so that it transfers a layer of wax to the surface of the paper as the latter passes over it. The paper then travels over a heated drum (like the drying cylinder of a paper machine), the unwaxed side being in contact with the metal; the wax layer melts and penetrates the paper, without leaving any on the surface.

Dry-waxing may also be carried out on the paper machine calenders by means of water doctors (p. 156), though little is done in this country in this way. Waxing after manufacture is considerably more effective than is the addition of a wax emulsion to the pulp in the beater, since a larger proportion of wax may be added; it may in fact double the weight of the paper originally taken. Cartons and cups used for food, milk and ice-cream containers are usually waxed after they have been printed and shaped, by simple dipping. The wax thus seals the seams and corners and makes the carton more rigid. Waxed paper is widely used as a waterproof wrapping, *e.g.* for bread, confectionery and tarnishable metal goods.

Vegetable Parchment

This process depends on the fact that cold sulphuric acid converts cellulose fibres into a partly soluble substance which, when it comes into contact with water subsequently and is subjected to pressure, produces a dense, hard sheet, having a high resistance to penetration by grease, fairly good water-resisting properties and an excellent strength in the wet state. Such material, therefore, makes an excellent wrapping, especially for fatty foods (butter), and it is widely used for this purpose. A novel application, widespread in Germany, is the manufacture of sausage skins.

A web of pure, unsized paper, of cotton pulp for preference or of bleached sulphite or kraft, is passed through a lead-lined bath (like a small tub-sizer) containing cold 65–75 per cent. sulphuric acid. Usually, the immersion takes 3–10 seconds, according to the substance of the paper, and during this time the fibrous structure of the paper completely disappears and much shrinkage occurs.

The treated web next travels through a long series of lead-lined water-baths (the last of which are provided with sprays), which wash out the acid. These are so arranged that the weakest acid (in the last bath) flows back continuously to the bath preceding it, and so on back to the first washing bath after the strong acid. In this way the dilute acid washings are used to wash the more acid paper, and are thereby strengthened. The used acid is ultimately recovered to the extent of 90 per cent. by evaporation. One of the last baths contains dilute alkali (ammonia or soda ash solution) to neutralise the trace of remaining acid, and in the last bath of all is dilute glycerin or glucose, to prevent the dried paper from becoming brittle. The sheet is dried on ordinary drying cylinders under as high a tension as possible.

Up to five thin-substance webs may be laminated together by passing them together through the acid bath, for making products such as lampshade parchment or thin boards.

Vulcanised Fibre is similar to vegetable parchment in that the fibrous character of the cellulose is destroyed by chemical action, but in this case a warm 70 per cent. solution of zinc chloride is used. The process is otherwise the same, except that washing must be more prolonged. It is used when the final product does not have to come into contact with foodstuffs and when it is desired to laminate a number of sheets together in the bath. Hard, dense, strong, water-resisting boards, and imitation leather for luggage, can be made in this way.

Plastic-Treated Papers of various types are becoming increasingly widespread as a means of producing resistance to water, grease, gases and vapours, and some interesting results of this nature were obtained during the war of 1939–45 when it was necessary to evolve special wrappings for supplies to be used on beachheads and in tropical countries. Many plastics, however, are either too expensive or leave residual odours which rule out the papers in which they occur for many wrapping purposes. The plastic is either coated on to the paper by rolls from a bath (as in dry-waxing, p. 174), impregnated into it by an immersion process (as in tub-sizing), or even added to the fibres in the beater or at the wet end of the paper machine. The last method is the least satisfactory, as difficulty is experienced in retaining sufficient of the plastic on the paper; an exception is, perhaps, the type of resins made by combining urea or melamine with formaldehyde, which are used in this way to produce high wet strength in paper.

Both plastics which harden when heated (*thermosetting*) and those which harden when cooled (*thermoplastic*) are used for treating paper, and the method of operation obviously depends on these properties as well as on the physical state and solubility of the plastics. Thus, some are applied in the molten state and hardened by cooling; others are deposited from solutions in solvents which subsequently disappear by evaporation; whilst some are used as emulsions in water. If relatively large amounts of thermosetting plastic are added to the paper, the resulting product can be moulded by combined pressure and heat to produce flat shapes, such as trays, panels, plates, and so on, having good strength. Furthermore, by *laminating* sheets of such plastic-impregnated paper together by hot pressure, thick composites of great strength and good electrical and moisture-resisting properties may be built up. These can be cut and machined to give a great variety of products, ranging from gear wheels to table tops; wood grain or fancy patterned effects may be reproduced photographically on the surface, which can be given a high and unscratchable glaze.

Conditioning

Most ordinary machine-made printing papers (excluding those containing mechanical wood pulp) come off the paper machine containing 3–5 per cent. of moisture. If this figure is much higher, there is difficulty in obtaining a finish on the calenders without crushing; if it is very much lower, the paper is brittle. When a normally dried paper is allowed to stand in the atmosphere of an average printer's shop, it will gradually absorb moisture from the air until its own moisture content reaches 6·5–8·5 per cent., according to the humidity of the surroundings. As it does so it will expand, and what is more, the expansion in the *machine-direction* (wire-direction) of the sheet will be only about 1/10th of that in the *cross-direction*. As an example, if a square of an average paper having sides 10 inches long is completely wetted, then the machine-direction side will become about 1/400th inch longer and the cross-direction side about 1/40th inch longer.

These differences are due partly to the shake of the paper machine wire, which arranges only a proportion of the fibres in the cross-direction of the sheet (see p. 129); and partly to the release of the internal stresses set up as the result of the paper being dried under a tensile pull operating mainly in the machine-direction. Thus, hand-made paper expands when it is moistened, but equally in all directions, since the fibres are equally distributed. The desirability for cutting sheets of printing paper so that the longer edges run in the machine-direction should now be obvious. This applies especially to papers for offset lithographic work, which are damped during the printing operation.

If reams of paper straight from the mill are unpacked at the printers and made into a stack, then the edges of the sheets (being more exposed) will absorb moisture more readily than the centres and will expand first, thereby causing wavy edges. If it so happens that the surrounding air is very warm and dry (as in the neighbourhood of hot-water pipes), the paper will tend to lose moisture at the edges, which will shrink, again causing the paper to develop wavy edges.

Modern, fast-running printing machines depend for their efficient operation on the supply of absolutely flat paper. The suction devices which lift the paper into the feed of the machine will not grip a wavy edge, and a cockled or curling sheet will run into creases as it goes through the rollers of a printing machine. Similarly, if a paper is being printed in several colours, one at a time, and in the interval between two successive printings it expands (or contracts) owing to the absorption (or loss) of moisture, there will be ugly overlaps between the edges of the colours in some places and gaps in others (out-of-*register* effect). The importance of perfect register in map work is obvious. The problem is less acute with paper on reels, partly because the tight winding of the reel seals off the paper to a great extent against the effects of the surrounding atmosphere; and partly because such paper is usually printed fairly rapidly from the reel in one operation, so that there is no time for the atmosphere to exert any ill effect.

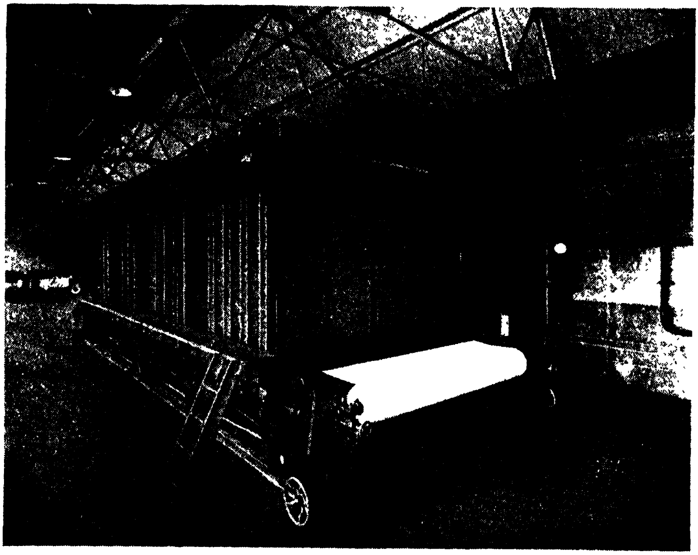

Fig. 73.—CONDITIONING PLANT FOR PAPER.

The difficulties encountered with flat paper are largely overcome by conditioning, *i.e.* by adding moisture to the paper so that it will neither give up nor lose very much under average working conditions. Formerly this was done by the printer, who hung up the sheets in loose wads in the room in which he intended printing them, until he felt that the desired state had been reached (*maturing*). Obviously, however, the desired result may be performed more efficiently at the paper mill before the paper is cut into sheets, and in a common form of conditioning machine paper is unwound from a reel and passed under and over a series of open drums (spar dryers, as used in a tub-sizing dryer, p. 170), around which moist air or steam is circulated. After the paper has travelled some distance in this way, it is re-reeled.

It is apparent that a limitation of this method is the difficulty of controlling the moisture content of the finished paper. This is overcome in the more modern type of plant (Fig. 73) by causing the paper to pass up and down in a series of vertical boxes, through which is also passed air which has itself been conditioned so as always to be at a particular temperature and humidity. The settings of the temperature and humidity controls of the plant which do this will thus determine the moisture content of the paper on the final reel. Such a machine also enables higher running speeds to be used, and it occupies much less space than does the spar dryer type of conditioner.

For most general purposes it is usual to work to a moisture content of about 8 per cent. in the final paper, and it is better to err on the high side, as the stresses are most effectively neutralised when the paper dries out slightly after having once expanded. The setting of the air-conditioning machine has to be varied according to the type of paper being made, as papers take up moisture at varying rates and to varying extents. Thus, papers which are thick or have a high finish tend to be slow in absorbing moisture from air. The presence of much china clay tends to help flatness, since the clay does not take up moisture to any great extent, and it certainly does not expand in doing so.

Finally, it should be pointed out that the advantages of conditioning in the paper mill will be largely wasted if the printer stores his paper in an atmosphere which is very moist (near an open door in damp weather) or very dry (near heating pipes). For this reason many up-to-date printing shops are themselves air-conditioned, and if the paper maker can condition the paper to match his customer's atmosphere, there is little chance that the troubles indicated above will arise.

Incidentally, conditioning also plays an important part in dispersing any static electricity produced by the action of the rolls of the paper machine on the dry paper (see p. 137). This is important, because it is not unknown for sheets in a stack to be held together so strongly by static electricity that they tear when pulled apart.

CHAPTER XII

THE PAPER MILL LABORATORY

THE PURPOSE of this chapter is to indicate the importance and scope of the laboratory in mill organisation. For reasons of space no description of equipment or details of analytical methods are included, as these are obtainable from the special books on the subject.

In a paper mill the designation "chemist" is usually employed to describe the person concerned with the technical control of mill operations and with the problems arising therefrom. It is largely a misnomer, because chemistry plays a relatively small rôle in such work. Chemistry is essential for the analysis of materials, and a knowledge of the laws governing the combination of substances and their action on one another is important, for instance, in connection with the preparation of pulp from a fibrous material or with the manufacture of special papers. Physics, however, is certainly of equal importance, as will be evident from examples quoted later in this chapter. It deals with the properties of matter as affected by heat, mechanical forces or other forms of energy; such as the effects on cellulose fibres and on the paper made from them of such forms of energy, in absence or in presence of water.

The most important qualification of the paper mill "chemist" is, probably, the scientific outlook—that is, the capacity to use knowledge systematically, to observe accurately, to view problems objectively and to deduce results logically.

The functions of the mill laboratory are conveniently classified into four main categories, namely:

(1) Examination and control of raw materials.
(2) Technical control of mill operations and products.
(3) Investigations of problems arising out of the above.
(4) Original research work.

This chapter follows these headings.

(1) *Examination and Control of Raw Materials.*—Work of this nature may itself be subdivided according as it deals with the investigation of proposed new supplies of raw materials and the routine examination of deliveries; it is convenient to consider the subject in this sequence.

Close co-operation between the purchasing department and the laboratory is not only a remunerative policy, but also in many cases it is essential if the former is to function to the best advantage. The buyer who knows exactly what a particular supply of a raw material is worth to the mill, without the risks and delay of a mill trial, can at once determine the maximum price at which it offers him any advantage over existing supplies; and, of even more importance, he is able to eliminate rapidly those supplies which would be of no use at any price. The principle of the chemist-buyer is, in most ordinary mills of any size, an undesirable one, because the laboratory should, above all, be impartial in its outlook. Moreover, the chemist may be fully aware of the technical value of a particular material, but he may not necessarily be capable of striking a good business bargain, which may have to take other important factors into account.

On the other hand, the laboratory cannot interpret its results without some knowledge of the price of the material being offered. Many of the testing methods used in paper mill work are based on comparisons between existing standards and the new supply, and a knowledge of relative costs is a valuable guide in assessing such comparisons. It can also save time, because one or two tests of a preliminary character often indicate whether a new supply is ruled out completely by its price or if it is worth further examination. The detailed tests which new materials must, for safety's sake, undergo, are in many cases lengthy, and not to be started unless likely to be justified.

The nature of the testing methods varies considerably according to the material involved. In some cases a chemical analysis is an accurate guide to value; *e.g.* the simple titration of soda ash for use in pulp manufacture. In others, however, it may be of little value. For example, the proportions of the elements present in a china clay give little information as to its value as a filling material for paper. Colour, particle size and freedom from grit are better criteria. The purity of the cellulose in a wood pulp might be important for fine papers for permanent records, but would be irrelevant for pulp to be used in cheap printings. In many cases it is necessary to simulate large-scale procedure, so as to obtain some idea how the material will behave in actual practice. Wood pulp affords an excellent example, because it is evaluated by beating for various periods of time, and making sheets of paper which are tested for strength and other properties (Fig. 74).

It is essential, however, that with the latter type of method the working conditions should be strictly standardised in every detail, so that the same results may be obtained time after time in the same laboratory and also in independent laboratories. The formulation of standard methods by responsible bodies (such as the Technical Section of the Paper Makers' Association in Great Britain, and the Technical Association of the Pulp and Paper Industry in the United States) has helped considerably in this direction (see p. 190).

This standardisation of methods, however successful as such, will fail in its ultimate object if it is not possible to correlate the laboratory results with mill operations. Actually, this may be a difficult matter, because a laboratory imitation of a mill operation is sometimes only an approximation. The evaluation of wood pulp is again an example: thus, the ball mill used in the laboratory beats essentially by hydration, whereas the usual mill beater cuts or fibrillates the fibres.

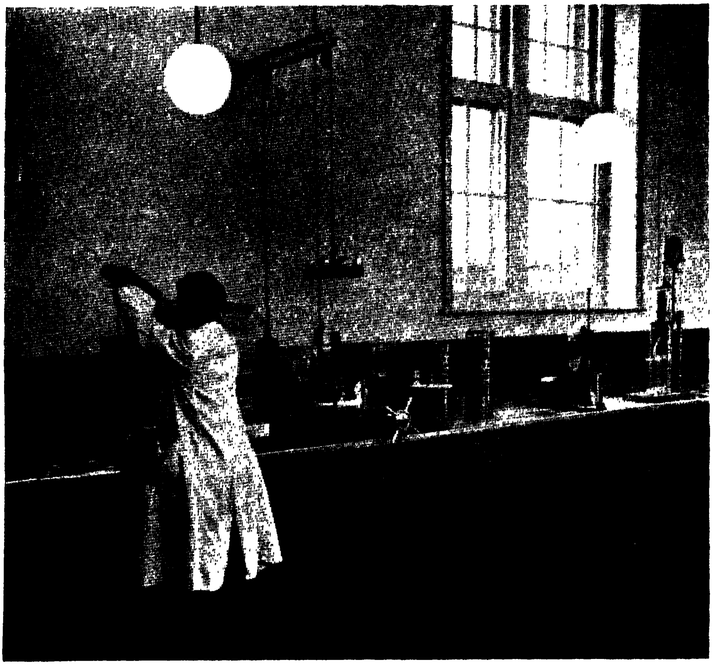

Fig. 74.—Laboratory Evaluation of Wood Pulp.

Where laboratory and mill methods fail to correlate quantitatively it is often possible to use an arbitrary factor to enable laboratory results to be translated into terms of mill practice. Such methods of correlation are quite sound if the testing procedure used can place a range of samples of the same material in the same order of merit as properly controlled mill trials. It is therefore both important and in the interests of all concerned that mill trials should be made.

It is next desirable to draw up a specification for quality, with which the supplier is asked to agree. The guiding principle should be to define the properties of the material in terms of the minimum number of actual tests, bearing in mind the purpose for which the material is to be used. Thus, with soda ash the alkalinity is obviously the test of principal importance, whilst (say) the iron content is of no significance if the soda ash is to be used for causticising purposes. An unnecessarily strict specification not only increases the work of the laboratory, but is unfair to the supplier; it may even recoil on its originator, because the manufacturer striving to attain an unnecessarily high standard in one respect may have to neglect some more essential requirement.

Difficulty sometimes arises when the supplier refuses to accept the suggested specification (or any specification) as the basis of a contract. This may be due to failure to appreciate the part played by his particular material in the paper making process or to differences in testing methods which give rise to apparent discrepancies. Such troubles are soon overcome by the co-operation which should exist between every supplier and consumer. Experience shows that, in general, the greater the degree of scientific control exercised by a manufacturer over his product, the less chary is he of accepting a specification. At the other extreme is the manufacturer who accepts the specification for the sake of securing the order, and trusts to luck and his own wits for the rest. In the long run he will usually prove less satisfactory to deal with than the manufacturer who is honest enough to refuse the specification at the outset.

It seems, therefore, that specifications, though desirable when their significance is fully appreciated by both sides, are not of necessity a "hall-mark." Nevertheless, the general trend in industry is towards the increasing use of specifications for materials; and the British Standards Institution has already published a number of useful specifications for finished paper and paper products. Quite apart from this, however, specifications are of great value for internal mill use, because they provide numerical standards of quality for raw materials.

The next stage, a mill trial on a small consignment, checks the laboratory conclusions and provides valuable information concerning any special properties of the new material; it also, to some degree, tests the extent to which the sample originally submitted is representative of the bulk supply. With the last object in mind, the quantity of material used for the mill trial should be as large as possible, so as to minimise sampling variations and give a reliable picture of behaviour under large-scale working conditions.

The difficulties of running a fair mill trial are easily underestimated. First, the trial has usually to be fitted into the normal production programme of the mill, and thorough preparations should therefore be made in advance. Another difficulty may be the reluctance of many operatives to depart from the methods and materials to which they are accustomed, and the personality of whoever is responsible for the trial is an important factor in eliminating this attitude. It is also essential that he should attend to the trial in person, checking every stage and measurement and making his own observations. At the same time, the views of the practical man who knows his job are to be respected, although they should, if possible, be put to experimental test.

If the mill trial is inconclusive and if special considerations make the use of the new material desirable (*e.g.* a shortage of existing supplies), a further trial should be made on a larger scale. In fact, where possible, this is always desirable, because difficulties may come to light which are not apparent from the short trial; examples are scale-formation or corrosion effects which take time to develop.

Equally important is the control of the quality of deliveries of raw materials of all kinds (including water), and representative samples of these should be made available in the laboratory as soon as deliveries come in. No material should be issued by the storekeeper until a laboratory report certifies that it is satisfactorily up to standard, and the flow of deliveries should be regulated and stocks maintained so that, in the event of an adverse report, there will be no temporary shortage.

The specifications already referred to will, of course, be very useful in work of this kind, although it is seldom necessary to apply the whole of the tests specified. Economy of such routine work is important, or the tests may cost more than they are worth. However, it is often possible to devise short-cut tests which give the essential information or serve as indicators of quality. For instance, in the evaluation of a new brand of wood pulp, strength and other tests must be made after a whole series of beating times; when deliveries come in, however, tests after one or two beating times will suffice, since it is reasonable to assume that if these are satisfactory, so also will be the whole series. Similarly, when a new well is started up a full analysis of the water is essential, but for routine control purposes a hardness and total solids test will usually suffice if the water is to be used only for mill processes.

When the laboratory facilities do not allow the necessary tests to be made on every delivery of every material, then a "snap" test from an occasional delivery is better than nothing. The argument that because supplies are always satisfactory there is no need to test them is a fallacy. First, it is often impossible to tell whether a material is below standard without a laboratory test. Thus, if a dyestuff is 10 per cent. low in strength, more of it will be used in the mill to obtain a given paper shade, but it is doubtful whether the extra consumption will be noticed for some time, and it is almost certain that if it is noticed it will be impossible to assess the loss of value with any accuracy. Moreover, if a supplier knows that every delivery he sends in is being tested, his natural reaction will usually be to play for safety; bad or border-line deliveries are thereby minimised. Practical experience has, in fact, shown that a well organised scheme of control not only enables the best value for money to be obtained, but results in a gradual rise in the general quality of all raw materials.

Defective deliveries will however, occasionally be received. At the one extreme is the delivery which is quite unusable under any circumstances, and here there is no alternative to rejection and replacement. Often, however, the delivery can (possibly with manipulation) be used without involving any great risk, and it is then usually best to retain it, so long as the supplier bears any extra costs involved in using it; these are usually less than those of replacement. The laboratory should be able to advise on the best action to take. An example, again, is that of the dyestuff which is below standard in strength. So long as allowance is made for the weakness it can be used without much trouble; if, however, the dyestuff is off shade, it can still be used, but the trouble and expense of introducing a correcting colour will be involved, and the user is entitled to compensation for these. A delivery of china clay may have an excessive moisture content, but it can still be used, although the price needs to be adjusted to allow for the extra water present. The policy of using "the customer is always right" axiom to enforce the acceptance of trivial complaints is to be deplored.

(2) *Technical Control of Mill Operations and Products.*—Here again, while the advantage of laboratory control cannot be disputed, the question frequently arises how far it can be carried economically; at what stage does control become too costly to be an asset? One answer is, that it depends on the use made of the results.

The most important and immediate use of control data is, of course, to ensure that operational faults are rectified with the minimum of delay (see below). Much useful information may, however, also be obtained from the statistical examination of accumulations of test data. Thus, tests on paper may be used to trace the characteristics of the paper machine on which it was made;

such as tendencies away from normal running and the effects of variations in the speed of the machine.

The managements of most paper mills will, however, turn to the more immediate applications as a means of justifying mill control. These are, to guide operatives in their work and to show whether the operations have been carried out efficiently. The principal criteria of tests of this kind are speed and accuracy, though the accuracy need be no more than is required by the circumstances. A case in point is the rapid determination of the moisture content of paper, in which the paper is dried in an oven to a low moisture content and weighed, and a fixed amount (determined from previous experiments) is added on to allow for the residual moisture; a result is thus obtained in about ten minutes which, though approximate, is adequate for routine control work.

Many mill operations may be controlled "in advance." Thus, recovered caustic soda is titrated in order to ascertain for the digester-house operatives the amount to take for the next boiling. Many operations can, however, still only be controlled "retrospectively." Beating is still in this category in many mills; it cannot be checked properly until a test sheet is available from the paper machine (see p. 97). Of great importance then is the rapid communication of the result to the person in authority. Local circumstances will determine the best procedure, but if the report is made direct to the operative concerned the foreman in charge should certainly be kept in touch.

Tests of this kind also have psychological value, since continuous checks on practical working usually result in greater care on the part of those concerned. The fact that no troubles are encountered (if this ideal state is ever reached) is therefore no argument against routine tests. It is very unfortunate however, if the laboratory comes to be regarded as a kind of secret police, and to avoid this calls for considerable tact and personality in those involved.

The greatest help will result from training operatives to be "laboratory-minded," for instance, by demonstrating to them in a simple way the operations and functions of the laboratory. It is good policy, therefore, to draw on promising young men who have spent a few years in the laboratory ultimately to fill key positions. Talks for operatives serve the same ends, especially if they can be given in simple language and illustrated by experiments. Thus, for instance beatermen might be shown fibres under the microscope at various stages of beating. All this is not such a far cry from the perfection of mill control as it may seem.

The routine report sheets will occasionally bring peculiarities to light, and when these occur they become matters for investigation by the main chemical staff, as distinct from the routine testing staff, who keep strictly to their appointed routine duties. This, therefore, brings us to the next division of the work of the mill laboratory.

(3) *Investigations of Mill Problems.*—Such work calls for a staff having higher qualifications. Capacity for original thought, for seeing a problem clearly, and a flair for the application of theoretical knowledge to practical ends are the principal essential qualities, but unfortunately this is a blend that is rarely forthcoming.

Day-to-day problems arising out of mill working (and these may include queries raised by customers, and complaints) must usually be solved as rapidly as possible, and the difficulties of carrying out scientific investigations to a time schedule are obvious. Care must nevertheless be taken to avoid hasty conclusions based on insufficient or unconfirmed evidence, and speed, however important, must remain a secondary consideration to this. However, paper and pulp are manufactured on big operating units, which turn out large quantities of product in a short time. If, for instance, the paper suddenly "comes" dirty, much defective paper may be made on a high-speed machine before the trouble can be found and eliminated.

Many bottle-necks in laboratory work arise from the time taken by analytical operations, and in the interests of accuracy these can seldom be hurried. The use of the most rapid methods available, consistent with the degree of accuracy required is, therefore, an important feature of internal laboratory organisation, and familiarity with the recent scientific literature of the subject is essential. There is a growing tendency on the part of official and semi-official bodies to formulate standardised methods of physical and chemical analysis; they have the advantage that they enable results obtained in different laboratories to be compared directly with one another. A case in point is the determination of the *p*H value of paper, since the result obtained depends on the technique used for the extraction of the sample, and this has varied considerably from one worker to another. Much useful standardisation work has been carried out in Great Britain by the Technical Section of the Paper Makers' Association and by the British Standards Institution; and in the United States by the Technical Association of the Pulp and Paper Industry (T.A.P.P.I.).

In dealing with mill problems there must be close and efficient co-operation between the mill and the laboratory, and someone should be delegated to divide his time between the pursuit of the problem in these two spheres. For instance, he should be responsible for taking any samples required, because the rapidly changing conditions of paper-mill work, and the many variables which enter into it, make it essential that samples are taken "first-hand."

Mill investigations are very varied. When a process is causing trouble because a particular operation behaves in an unexpected manner, when somebody in authority has what he believes to be a bright idea, when a customer complains that his paper is unsatisfactory, or when anything abnormal happens, then the chemist is expected to produce a satisfactory report. Some of the problems are straightforward; others may involve much fruitless work; a few may appear to be unresponsive to any treatment.

Thus, a common trouble in a mill making white paper is dirt specks in the sheet. Some specks respond to chemical or microscopical examination, but many are difficult to identify with a particular cause, and familiarity with the mill may be helpful in locating their origin. It may be possible to associate them with particular pulps, with broke, with a particular water supply, with the direction of the wind, with a certain hour of the day or with some other change in conditions. Again, soda recovery plants provide many problems, such as the extent to which recovery is economically justified, the prevention of scale in evaporator tubes, reduction of maintenance charges, and improvements in the efficiency of sludge washing. New testing methods of analysis, testing and evaluation of materials have to be tried out for accuracy and economy of time or labour. The list of problems might be extended almost indefinitely.

Fig. 75.—Corner of a Typical Paper Mill Laboratory.

In the same category are the problems which arise after the paper has left the mill, including complaints. In such cases, a difficulty frequently experienced is that of obtaining adequate information and samples. The investigation of a user's problem by a technical representative, on the spot, is the most satisfactory (and in some cases the only) method of dealing with such problems. Second-hand information obtained by correspondence or through non-technical personnel is nearly always lacking in some important details, or is even misleading. The technical men of both parties can meet on common ground and, assuming full co-operation, it is seldom that a solution cannot be found in the minimum of time. Incidentally, contacts between technical staffs in this way often develop very favourably to business relationships, and under normal trading conditions expert "service" of this kind is a recognised sales asset.

It seems undesirable, however, that the actual settlement of the complaint should be in the hands of a technical representative of this type. His investigations should be unbiased and, therefore, untrammelled by non-technical considerations. Of course, his report should be made direct to his own executive, and he will reasonably be expected to provide a "case" for his firm's interests when a dispute arises.

(4) *Original Research Work.*—The term "research" is used somewhat indiscriminately (and often inaccurately) to describe a number of very different forms of scientific activity. Research essentially involves originality, as distinct from routine work, the application of known methods and the mere accumulation of measurements. Almost every problem of paper-mill science can therefore be brought under this heading to some extent. The type of research work with which we are now concerned deals with fundamental scientific problems, as distinct from day-to-day queries, and it may extend over a long period of time. If past experience is any guide it will be recognised that such work pays in the long run. On the other hand, the "run" may be very "long" indeed, and few firms are disposed towards (or can afford) these long-term investments.

If such work is to be undertaken in earnest, it is necessary to employ scientific workers having the rare blend of qualifications indicated above under (3); and it is unlikely that they will be able to assist in the other work of the laboratory without detriment to their research activities. In addition, special equipment and probably specialised small-scale plant (which may be expensive to instal and have no value once it has served its purpose) may be required; and expenses of this kind may continue for a long period of time. Finally, there is always the possibility that the work may yield no financial return, although (unless it is grossly misdirected) it is almost certain to have results of scientific importance.

Long-range research in the paper industry, therefore, is not often initiated in the mills themselves, but is largely confined to organisations (such as trade research associations, universities and technical colleges) associated with the industry. The necessary financial support has always been readily forthcoming from the industry, so that much of the long-range research into the basic principles of paper manufacture has been an indirect result of co-operation by the industry as a whole. This same spirit has shown itself strikingly in Great Britain by the formation, in 1945, of the British Paper and Board Research Association. This is financed jointly by the Paper Makers' Association of Great Britain and Northern Ireland and the Government (through the Department of Scientific and Industrial Research). The Laboratories of the Association are now engaged on a wide range of problems covering the varied interests of the industry. These are based on suggestions made by member firms, and representatives of these firms sit on the various advisory technical and other committees and panels.

The results of the work are made available to member firms only, and in this respect all members have equal privileges. The advantages of membership of such an Association are obviously great, but they are in no sense a substitute for any of the activities of the paper-mill laboratory as set out above. The Research Association is equipped with apparatus and staff essentially to deal with long-range fundamental research on the scientific aspects of the subject; the mill laboratory is concerned with the application of the results to the practical ends of its own mill, in addition, of course, to its other activities as set out in sections (1) to (3) above. Thus, it starts where the Research Association leaves off, and each is essential to a progressive firm.

Testing Methods

This chapter would be incomplete without some notes on testing methods, since such methods figure prominently in all four of the types of mill laboratory activity listed above. However, the subject is so wide that it is possible to deal with it only very briefly and in general terms.

Testing methods, whether for pulp, other raw materials, mill processes or finished paper, fall into two main groups, namely chemical and physical. In general, the former serve to identify and measure the amounts of the constituents present; examples are the determinations of the ash, rosin content and acidity of paper, the alumina content of "alum," and the alkalinity of caustic soda. The physical methods, on the other hand, deal with the properties of the material or substance being examined, and typical examples of this nature are the strength, colour and water-resistance of paper, the coarse particle content of china clay, and the capacity of wood pulp to develop strength on beating. However, there is no sharp line of demarcation between chemical and physical testing methods. Thus, the identification of paper-making fibres and the examination of dirt specks in paper each involves both types of method.

In general, chemical testing involves the application of well-known chemical analytical methods to the substance in question. Thus, to take the above examples, the methods for determining ash, rosin and acidity are substantially the same whatever the nature of the actual sample; there are of course minor variations in procedure, but the basic principles are the same.

With physical methods, however, the position is different, because the same property may have different meanings (and therefore require different methods of evaluation) according to the nature of the substance under test. Thus, the strength of paper is entirely different from the strength of (say) metal wire, and the methods of evaluation differ correspondingly. In consequence, most physical tests for paper are empirical in character, that is, they measure one special property by a specified procedure. So long, therefore, as the working conditions are strictly standardised, the same result should be obtained for the same paper in different laboratories.

Unfortunately, the evolution of such methods has taken place in an uncontrolled fashion over some period of time, each worker following his own ideas on the subject and often with little reference to the work of others. The result has been much duplication of effort; for instance, there are over fifty so-called "sizing tests." As already stated, official organisations in many countries have organised investigations into the advantages and drawbacks of existing tests, and the standardisation of methods and apparatus, so as to minimise discrepancies between independent workers and yet give the truest expression of a particular property of a paper.

Strength properties are an illustration of the difficulties involved, since with paper "strength" may mean resistance to bursting, a tensile pull, folding, tearing, bending, etc.; each is important in connection with the varied uses for paper. The more subtle characteristics of paper, such as colour, gloss, brightness and finish, involve specialised testing problems of their own, particularly when they are to be given numerical values.

Further problems associated with physical tests on paper are the difficulty of obtaining a truly representative sample of a large quantity of paper, and the fact that the values obtained in many physical tests are dependent on the moisture content of the atmosphere in which they are made. The former may to a great extent be overcome by following standard sampling rules, although the heterogeneous structure of paper can still introduce variations. The folding resistance test, for instance, is made on a very small area of paper, which may easily be much stronger or weaker than adjacent areas. The only way to minimise variations due to this is to take the average of a large number of tests.

The second difficulty is overcome by exposing the samples, before testing, in an atmosphere of controlled relative humidity and temperature until their moisture contents no longer change further; the test is then made in this same atmosphere. For this purpose every well-equipped paper-mill laboratory requires a room (or a large cabinet) which can be so controlled. The standard conditions usually adopted in Great Britain are 65 per cent. relative humidity and 70° F., and the same tests made in different laboratories on samples so conditioned are then directly comparable. Strength tests (and especially folding resistance measurements) are particularly susceptible to variations of this character.

READING LIST

Anon., "Book Construction," 1931 (London: Library Association).

Clapperton, R. H., "Paper Making by Hand; an Historical Account," 1934 (Oxford: Shakespeare Head Press).

Clapperton, R. H., and **Henderson, W.**, "Modern Paper Making," 3rd ed., 1947 (Oxford: Blackwell).

Cross, C. F., and **Bevan, E. J.**, "Text Book of Paper Making," 5th ed., 1920 (London: Spon).

Dawe, E. A., "Paper and its Uses," vol. I, 4th ed., 1939; vol. II (paper samples), 1929 (London: Technical Press).

Dorée, C., "Methods of Cellulose Chemistry," 2nd ed., 1947 (London: Chapman and Hall).

Grant, J., "Laboratory Handbook of Pulp and Paper Manufacture," Reprinted, 1948 (London: Arnold).

Grant, J., "Wood Pulp and Allied Products," 1947 (London: Hill).

Hunter, D., "Paper Making. The History and Technique of an Ancient Craft," 2nd ed., 1947 (London: Pleiades Books).

Heuser, E., "Chemistry of Cellulose," 1944 (London: Chapman and Hall).

Joint Textbook Committee of the Pulp and Paper Industry of the United States and Canada, "Manufacture of Pulp and Paper," 3rd ed., vol. III: "Manufacture of Pulp," 1937; vol. IV, 1938, and vol. V, 1939; "Manufacture of Paper" (London: McGraw-Hill).

Leicester, S., "Practical Studies for Paper Manufacturers and All Engaged in the Industry," 1933 (London: Griffin).

Sindall, R., "Paper Technology," 3rd ed., 1920 (London: Griffin).

Sutermeister, E., "Chemistry of Pulp and Paper Making," 3rd ed., 1941 (New York: Wiley).

Various Authors, "Technical Association Papers." Published annually (New York: Technical Association of the Pulp and Paper Industry).

Williamson, H., "Lessons in Paper Making," vol. I, 1928; vol. II, 1929 (Chicago: Fritz).

Witham, G. S., Sr., "Modern Pulp and Paper Making," 1942 (New York: Chemical Catalog Co.).

Publications of the Technical Section of the Paper Makers' Association:

- Second Report of the Pulp Evaluation Committee to the Technical Section, 1936.
- Standard Method for the Determination of the Thickness and Bulk of Paper, 1936.
- British P.M.A. Testing Methods for Paper (Published separately).
- For Your Safety, 1948.
- Proceedings of the Technical Section (Published annually).
- Technical Bulletin (Published quarterly).

PAPER-MAKING TERMS

Special paper-making terms used in this book are shown in italics and are defined or described on the pages represented by the numbers opposite the term in the following list. Where a term is used in the paper industry in more than one sense, the corresponding page references are given. Other references in the book to a particular term may be found from the Index.

Terms not defined fully or not mentioned in this book are defined separately in the Glossary below.

Abietic acid, 105
Acid process, Bisulphite process.
Agalite, 110
Air mail paper, 34
Alfa, Esparto.
Alkaline processes, 79
Alpha pulp, 78
Alum, 107
Aluminium resinate, 107
Aluminium sulphate, Alum,
Angle cutter, 167
Aniline dye, 111
Animal parchment, 11
Animal tub-sized, 168
Annaline, 110
Antichlor, 89
Antique, 154
Apron, 126
Art paper, 31
Asbestine, 110
Asbestos, 111
Ass, 118
Available chlorine, 83

Baby press, 154
Back tenter, 138
Backfall, 56
Backwater, 130
Bagasse, 49
Banger, 55
Bank, 48
Bar, 56
Barium sulphate, Barytes.
Barking, 72
Barytes, 110
Base paper, Body paper.
Basis weight, Substance.
Bast fibre, 36
Batter, 132
Beating, 95
Bellmer, 85
Bedplate, 56
Bible paper, India paper.
Bisulphite pulp, 68, 77
Bitumen paper, 34
Black ash, 65
Black liquor, 60
Black nip, 155
Blanc fixe, 110
Bleach liquor, 83
Bleaching, 83
Bleaching powder, 83
Blotting paper, 28
Board, 140
Body paper, 31
Boiler, 54
Bond, 48
Bowl, 160
Breaker, 54, 174
Breast box, 124
Breast roll, 126
British gum, Dextrin.
Broke, 122, 167
Brush finish, 173
Brushing-out, 97
Bulk, 40
Bull sliver screen, 75
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GLOSSARY

Agitator.—A rotating device for mixing stuff in a chest.

Air-dry.—Describing (1) the moisture content of a substance when the latter neither loses nor gains moisture on exposure to the surrounding atmosphere; (2) wood pulp containing approximately 10 per cent. of moisture.

Alum.—Correctly, a general name for a member of a group of double sulphates, all of which crystallise in the same form (*e.g.* potash alum). In paper making, aluminium sulphate.

Aluminoferric.—A commercial name for a mixture of iron and aluminium sulphates; used for sizing paper and for water treatment.

Apparent specific gravity.—The ratio of the substance of a paper to its thickness; it is the reciprocal of the bulk.

Aspen.—*Populus tremuloides,* a tree of the poplar family, used for making a relatively soft soda pulp.

Azure.—Describing a paper having a pale blue colour, usually a ledger paper.

Baffle.—A device which obstructs the movement of a fluid, and so aids mixing or retards the rate of flow.

Bagasse.—Sugar cane residues, after the sugar has been extracted; used for making pulp for paper.

Baumé, Beaumé, Bé.—A hydrometer scale for the expression of the specific gravity of a liquid.

Bee's sting.—A small hole in paper caused by excessive suction at the suction boxes.

Bellmer.—A horizontal chest for storing or bleaching pulp, in which the contents are pump-circulated around a central partition.

Bells.—Crater-like markings in paper, caused by the bursting of a bubble in the stock on the wire of the paper machine.

Biscuit cap.—A thin, usually M/G, wrapping.

Blanc fixe.—Barium sulphate, produced by chemical reaction, and used for coating paper.

Blind spot.—A spot in a paper-machine wire where the mesh has become filled up, *e.g.* with grease or resin.

Blow box.—A vacuum box under a wet press felt, which obviates blowing (see below) by removing air from between the felt and the paper.

Blow pit.—The receiver into which the pulp from a digester is blown at the end of a cook.

Blow roll.—A light roll resting on the paper web to press it on the wet felt before it enters the press, thereby preventing blowing.

Blowing.—The formation of air bubbles between the paper and the wet felt as they enter the nip of a press.

Bone dry.—Describing a substance which is completely free from moisture.

Breaking length.—A measure of the tensile strength in relation to paper substance. The usual method of expression gives it in terms of the maximum length of a strip of paper, in metres, which will just sustain its own weight when hung from one end.

Bristol board.—A high grade of white pasteboard.

Brush-coated paper.—Paper coated on a separate machine, as distinct from paper coated on the paper machine.

Brush doctor.—A rotating brush, usually of wire, used to clean the surface of an M/G cylinder.

Burlap.—Coarse, woven jute fabric, used for paper making.

Burst factor, Burst ratio.—Methods of expressing the bursting strength of a paper in relation to its substance.

Cable paper.—Paper, in narrow strips, for spirally wrapping electrical conductors.

Caliper.—The thickness of a sheet of paper.

Camber.—The slightly greater diameter of a heavy calender or other paper-making roll, at the centre, as compared with the ends. It compensates for the weight of the roll.

Camber bar.—A convex-shaped bar, over which a paper web is passed to smooth out creases.

Cap.—Thin wrapping paper, as used in retail shops.

Carbon paper.—Tissue paper coated with a mixture of a fatty substance and a dark-coloured pigment; used for duplicating purposes.

Casein.—A nitrogenous constituent of milk, an alkaline solution of which is used as an adhesive, *e.g.* in the coating of paper.

Casing.—A grade of wrapping paper, usually 46 × 36 inches in size.

Centre.—A steel, wood or cardboard tube on which paper is reeled.

Chromes.—Bright yellow or orange, synthetically produced, lead chromate pigments; used for colouring paper in the beater.

Condenser paper.—A tissue used as the dielectric in electrical condensers.

Cord.—A unit of measurement of the volume of piled pulp wood (128 cubic feet).

Couch jacket.—A woollen felt covering for a couch roll.

Crash finish.—An embossed paper finish, resembling that of the fabric crash.

Crushing.—The irregular formation produced in paper on the paper machine when it is subjected to excessive pressure while wet.

Curlers.—Small rolls of pulp, *e.g.* formed by leakage of pulp under a deckle strap.

Dancing roll.—A roll for leading a web of paper, mounted on sprung bearings.

Dandy pick.—A hole in paper caused by the dandy roll removing a small clot of pulp.

Dandy worm.—A worm-like mark in paper caused by the formation of a bubble on the dandy roll.

Decalcomania.—A transfer paper for conveying a design to pottery, etc.

Decker.—A machine for concentrating pulp by extracting the water through a wire-covered cylinder fitted with a couch roll.

Deflocculation.—The reversal of flocculation; dispersal of a flocculent material into a finely divided form.

Den.—The recess in the floor of a hollander in which the bedplate is set.

Detail paper.—An unoiled, translucent tracing paper.

Dextrin, British gum.—Starch which has been treated chemically to improve its properties as an adhesive.

Doubling roll.—A roll for supporting a felt, used in conjunction with a stretch roll on a paper machine.

Drainer.—A chest having a perforated base, in which wet pulp is drained.

Draw.—The pull that paper undergoes when being transferred from one section to the next on the paper machine.

Dry felt.—A felt, usually of woven cotton, wool, asbestos, or a mixture of these fibres, which holds damp paper against the surface of a drying cylinder.

Ductor.—A sheet metal trough or strip which aids in leading the paper web through a machine.

Elbow bedplate.—A beater bedplate having bent bars.

Elongation.—An increase in length due to stretching.

Fast.—(1) Describing a dye which is relatively unaltered on exposure to light and air. (2) Describing a free pulp (American usage).

Featherweight.—A printing paper having a very high bulk and usually containing a high proportion of esparto.

Ferro base.—Describing a paper suitable for making ferroprussiate blue-print paper.

Fine Papers.—Papers of relatively high quality, such as those containing rag and/or esparto pulps, as distinct from those consisting of mechanical or even chemical wood pulps. However, the term is loosely used, and there is no sharp dividing line based on furnish.

Fireproofed.—Describing paper which has been treated to render it resistant to fire; such papers are not necessarily fireproof.

Flat warp.—A paper-machine wire having flattened warp wires.

Flong.—A hard board used for forming stereotype moulds.

Flour.—The fine fibre débris produced when grinding wood in the manufacture of mechanical wood pulp.

Fluff.—Fluffy aggregates of fibres and fibre débris removed from paper surfaces during the drying and subsequent operations.

Folding strength.—The number of double folds which, when applied to a strip of paper under specified conditions, causes it to break.

Folio.—(1) A sheet of paper in its full standard size. (2) In book production, describing a paper sheet which has been folded only once; or a book of such sheets.

Frame washer.—A wooden frame covered with wire cloth and placed under the roll cover of a breaker to separate dirty water during the washing of rags, etc.

Fugitive.—Describing a dye which changes in strength and/or shade on exposure to light and air.

Gelatine.—A nitrogenous constituent of skin and bones, used as a size.

Greaseproof paper.—A paper which resists penetration by oil or grease, though not necessarily completely.

Guard board.—A board the edge of which is pressed against the jacket of a top couch roll, to remove pulp and water, and also any adhering pieces of paper.

Gum rosin.—The residue left after distillation of turpentine from the resinous exudation of coniferous trees.

Holocellulose.—The total carbohydrate constituents of wood.

Hydrometer.—An instrument for measuring the specific gravity of a liquid.

Hygrometer.—An instrument for measuring moisture content (*e.g.* of the atmosphere).

Imperfect.—Describing, collectively, seconds, retree and broke paper.

In and in.—A method of packing very large sheets of paper by folding the reams into a U-shape and fitting them into one another.

Indicator.—A dyestuff, the solution of which changes colour when its pH is altered; used to measure pH values.

Insides.—The eighteen inside quires of a ream of writing or drawing paper; usually applied to hand-made papers.

Intaglio.—A printing process in which the pattern is cut or etched in the printing surface, and filled with ink which is subsequently transferred to the paper surface.

Interleaving.—The insertion of paper between printed sheets to prevent contamination by undried ink.

Intermediate calender.—A calender between two sections of the driers of a paper machine.

Iron oxide pigments.—Black, red, brown and purple pigments prepared from iron oxides and used for colouring paper in the beater.

Jacquard board.—A board used on a jacquard loom for the production of woven patterns.

Jordan refiner.—The original cone-type refiner.

Leading roll.—A light roller, which supports paper or felt.

Leather board.—Correctly, a board made from leather scrap. It now often contains brown mechanical pulp.

Ledger.—Usually a strong, tub-sized, rag paper having an azure tint.

Letterpress.—A method of printing from type in relief, which is inked and applied to the paper.

Lifting.—Picking.

Litho.—Abbreviation for lithography, a process of printing from a flat surface.

Loan.—A very strong, long-fibred, tub-sized, rag paper; used mainly for legal documents.

Lodger.—A lump of pulp adhering to a corner or side of a beater, strainer, or breast box, etc., and becoming detached subsequently.

Long crimp.—Describing a paper-machine wire having a twill weave.

Machine direction.—The direction of a sheet or web of paper corresponding with the direction of travel of the paper machine.

Manifold.—(1) A slightly-waxed, tissue interleaving paper; (2) a very thin typewriting paper, used for making a large number of carbon copies; (3) a wide pipe leading into a digester, into which the various inlet and outlet service pipe-lines pass.

Manil(l)a.—A coloured paper, usually buff, used principally for making strong envelopes, folders, etc., but not necessarily containing manila fibre.

Marking felt.—A wet felt having prominent warp threads; used to produce ribbed surface effects, usually on an M/G machine.

Marking roll.—A rubber roll having a device in relief applied under pressure to the web of paper, usually on the first drying cylinder. It produces an imitation of a watermark.

Mica.—Small flakes of magnesium silicate, often present in china clay.

Micrometer.—An instrument for measuring small distances accurately, *e.g.* the thickness of paper.

Mottling.—A silurian effect, in which the contrasting fibres are relatively short, large in number, and lightly dyed.

Mucilage.—The thick solution or paste formed by certain gums in water; it often has adhesive properties.

Mulch (Mulsh) paper.—Paper for laying on growing plants, to protect the roots.

Nature brown.—A wrapping paper made mainly from brown mechanical pulp.

Needle paper.—An acid-free, black paper, used for wrapping needles.

Nozzle, Doll head.—The steam and/or condensate connection of the trunnion of a drying cylinder.

Ochre.—A yellow, red or brown iron oxide pigment.

Offcut.—Paper of usable size obtained as a by-product when larger sheets or reels are cut down to the size of the order.

Offset.—(1) A method of printing in which the ink is transferred to the paper via a rubber blanket; (2) the transfer of undried ink from a printed sheet to an adjacent sheet in contact with it.

Off-shade.—Describing the shade of a paper which differs slightly from that specified.

Onion skin.—A highly glazed, very thin, translucent paper.

Outshots.—A relatively low grade of white rags.

Outturn sheet.—A sheet of paper sent from the mill as representative of a particular making.

Oxycellulose.—A degraded form of cellulose, produced by oxidation.

Pams.—A grade of waste paper, correctly consisting of old pamphlets.

Papier maché.—Material produced by moulding wet pulp or repulped waste papers to a desired shape.

Pasting.—Any thin paper, usually M/G, used for pasting purposes.

Perfect.—(1) Describing a ream of paper consisting of 516 sheets, as compared with a mill ream containing a different number; (2) describing good paper, as distinct from retree, seconds or broke.

Peripheral speed.—The actual velocity of a point on the circumference of a rotating member, as distinct from the rate of rotation of the member.

Permeability.—The rate at which a fluid, usually air, passes through a sheet of paper under prescribed conditions.

Photogravure.—A method of printing by an intaglio process.

Picking.—The breaking away of the surface of a coated or uncoated paper, *e.g.* by the pull applied during printing.

Piping.—The ridges which form in a reel of paper, on standing, due to the absorption of moisture from the air.

Plastic, Synthetic resin.—A member of a large class of synthetic organic substances, which is plastic at some stage of its manufacture and can be moulded into a shape by heat and pressure. Used to coat or impregnate paper to impart special properties to it.

Points per pound.—An expression of the bursting strength of paper relative to its substance, in pounds per ream double-crown (480 sheets).

Porosity.—The property of paper due to the presence of pores or minute passages in it; sometimes used to indicate permeability.

Pottery tissue.—A thin paper used for the transfer of designs to pottery before the latter is finally kilned.

Precipitate.—To throw a chemical substance out of solution, in an insoluble form, by the addition of another chemical substance.

Pressboard.—Tough, highly glazed boards, used to smooth fabrics (especially of wool).

Pressing.—Paper, usually, M/G, used for the covers of exercise books and pamphlets.

Presspahn.—Pressboard.

Pure.—Wood-free.

Rattle.—The indication of the hardness and density of a sheet obtained when it is made to vibrate in the hands.

Relative humidity.—The weight of water vapour actually contained in a given volume of air expressed as a percentage of the maximum weight of water vapour which could be contained in that same volume (*i.e.* at the saturation point at the same temperature).

Remake.—The remanufacture of an order of paper which was previously made unsatisfactorily.

Retention.—The percentage of the amount of a loading (or other substance) added to the beater which is retained in the final sheet of paper.

Ribbed.—Describing the pattern produced on the surface of a paper by a marking felt.

Riding roll.—A light roll resting on the web of paper on a suction couch roll.

Rope carrier.—Ropes running outside the edge of the paper web, for leading the tail of the paper web through the paper machine after a break.

Rotogravure.—A method of gravure printing for paper on reels using engraved rollers.

Royal hands.—A size of writing paper, 24 × 19 inches.

Salt cake.—Commercial sodium sulphate.

Satin white.—A white pigment for coating paper, made from milk of lime and alum.

Saveall.—(1) A tray under the wire of the paper machine to catch the water draining from the stock; (2) a device for separating solids, fibre and loading from the water in backwater.

Shiner.—A shining particle in paper, due to mica in the china clay added as loading.

Show-through.—The appearance of print on paper, as seen through another sheet of paper placed over and in contact with it (compare Strike-through).

Side run.—A narrow reel of paper run with an order for larger reels, in order to fill up the full width of the paper machine.

Size.—(1) Originally, a solution of glue or gelatine; (2) a substance which reduces the rate at which a material containing it absorbs water.

Skip.—A thin brown paper, used for lining crates or for dress patterns.

Slow.—Describing a wet-beaten (or slow draining) pulp (American usage).

Smalt.—A blue, light-fast pigment, consisting of ground cobalt silicate.

Spent liquor.—The liquor produced during the digestion or bleaching of pulp.

Spindle reel.—A reel the centre of which is driven by means of the spindle on which it is threaded.

Spinning paper.—Paper strip for spinning into yarn.

Splice.—A join of two webs of paper, *e.g.* in a reel, or joining two reels.

Spreader roll.—A roll carrying a felt and having circumferential ridges so placed that they keep the felt stretched laterally (compare Stretch roll).

Staining.—A method of colouring a paper by treating it in the web with a solution of a dyestuff, as an after-process.

Steep.—A tank, often having a perforated base, in which pulp is stored, *e.g.* during bleaching.

Stereo.—A cast duplicate of type or printing blocks moulded in flong.

Strawboard.—Correctly, a board made from crude, unbleached straw pulp; often a substitute made largely from waste papers.

Stretch roll.—The adjustable roll used to take up the slack of a wire or felt and to maintain it under the correct longitudinal tension (compare Spreader roll).

Surat tares.—Raw jute, used for paper making.

Tackle.—The bars in the roll and bedplate of a beater.

Tail.—The narrow, often pointed end of paper by which the web is led through the paper machine.

Tear factor.—The expression of the resistance of a paper to tearing in relation to its substance.

Template.—A rectangular piece of thin metal or wood, used to facilitate the cutting or tearing of a sheet of paper to the desired dimensions when weighing it for substance.

Tendering.—The weakening of fibres, *e.g.* by the retting of rags.

Thickener.—A machine used to increase the consistency of pulp.

Thrasher.—(1) A machine for loosening dirt on rags or waste papers; (2) a revolving paddle for cleaning a felt by striking it.

Transfer paper.—A thin paper, coated with layers of starch and gum, used for transferring designs printed on it to pottery or other surfaces.

Trim.—The maximum width of paper which can be made on a paper machine after the edges have been trimmed off.

Triple warp.—A fine, woven wire, specially suitable for tissues, the warp wires of which are in trios.

Tunnel (trunk) drier.—A drying chamber, through which coated board or paper passes while hot dry air is circulated around it.

Twaddell, Twaddle, Tw.—A hydrometer scale for expressing the specific gravity of liquids.

Umber.—A red or brown pigment containing manganese oxide and silicate and iron oxide; used to colour paper.

Valve hook.—The hooked iron rod for lifting the emptying valve of a beater or other vessel.

Warp.—The thread running parallel to the length of a woven textile or wire fabric.

Weft.—The thread running across a woven textile or wire fabric.

Wet expansion.—The percentage increase in the length of a strip of paper after immersion in water.

White straining.—The straining of bleached pulp (compare Green straining).

Wiper.—A piece of wet felt hung against a dandy roll to wipe off particles of pulp.

Wiremark.—The diamond-shaped pattern of the paper-machine wire, seen on the wire side or in the look-through of a paper.

Wire side.—The side of a sheet of paper which was in contact with the wire during its formation.

Wood-free, Pure.—Describing a paper containing no fibres other than those of chemical wood pulp.

Wood resin, Pitch.—The resinous matter which occurs naturally in wood.

Yellow wove.—Misnomer for an azure wove paper having a greenish cast.

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